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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

CONTRIBUTIONS TO THE HYDROLOGY OF EASTERN UNITED STATES

1904

MYRON L. FULLER
GEOLOGIST IN CHARGE

WASHINGTON
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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., March 31, 1904.

Sir: I have the honor to transmit herewith a manuscript, entitled "Contributions to the Hydrology of Eastern United States, 1904." This paper is the second of a series of contributions relating largely to the hydro-geology of the eastern portion of the country, the first having been published as Water-Supply and Irrigation Paper No. 102, and has been prepared as the result of investigations of underground currents and artesian wells, as authorized by law. It includes 23 short papers by 19 geologists, physicists, and others connected with the eastern section of the division of hydrology. The aim is to present the results of subordinate lines of investigation which, because of their limited length, do not warrant separate publication.

A number of points of unusual interest are considered in the report. A full description of the electrical apparatus devised by Prof. C. S. Slichter for measuring underflow is presented for the first time. The description of the experiment at Quitman, Ga., for determining the liability to pollution of deep wells is an account of a practical investigation which proved to be of great importance in preventing steps that might have led to a serious contamination of the underground waters and a possible epidemic.

Very respectfully,

F. H. Newell,
Chief Engineer.

Hon. Charles D. Walcott,
Director United States Geological Survey.

CONTRIBUTIONS TO THE HYDROLOGY OF EASTERN UNITED STATES, 1904.

M. L. FULLER,
Geologist in Charge.

INTRODUCTION.

By M. L. FULLER.

OBJECT OF REPORT.

The present paper, which is the second of the series of "Contributions to the Hydrology of Eastern United States," includes 23 short reports by 19 geologists and others. Of these the longer papers have been contributed by those connected with the eastern section of the division of hydrology, but several that embody summaries of the water resources of regions covered by geologic investigations have been prepared by members of the geologic branch. The aim in preparing the report is to present the results of subordinate investigations, the length or scope of the reports of which do not warrant their publication as separate papers. In this way there is presented a considerable amount of material of local interest, especially in regions where complete investigations are not practicable. The paper is also intended to afford opportunity for publication of the results of laboratory or other physical, mechanical, or mathematical investigations bearing on underground water supplies.

SUMMARY.

The papers included may be briefly summarized as follows:

Description of the Underflow Meter used in Measuring the Velocity and Direction of Underground Water, by Charles S. Slichter.

The electrical apparatus described in this paper is intended to replace the inaccurate estimation of underflow based on size of material and head, and the troublesome chemical method. Commonly the test wells required by the present method consist of a group of four

2-inch driven wells, one located on the side from which the flow is expected and the other three in the arc of a circle 4 or 6 feet in radius on the downflow side. These are from 24 to 30 inches apart. Electrical connection is made with each well and the upstream well is charged with sal ammoniac or other electrolyte. The appearance of the salt at or near any one of the lower wells is recorded by an electric device, of which there are two types, nonrecording and recording. A full description of the construction and use of the apparatus is given.

The California or "Stove-Pipe" Method of Well Construction, by Charles S. Slichter.

In the larger number of the wells in the gravels, sands, etc., of the Coastal Plain regions of the Atlantic States and elsewhere, the hole is tightly cased throughout, the only point of entrance for the water being at the bottom. Only one water bed can be drawn upon in such wells. In California, and to some extent elsewhere, however, a method is in use whereby, by means of casings perforated at intervals, water can enter the well at a number of different levels. The casing consists of a steel shod "starter," 15 to 25 feet long, and sections of steel pipe 2 feet in length overlapping with flush joints. The casing is forced downward, length by length, by hydraulic jacks to the desired depth. In one well a depth of over 1,300 feet has been reached. After the well has been forced to the required depth a cutting knife, two types of which are figured in the paper, is lowered and slits or holes are cut through the casing at the points where, according to the record, water is known to occur. As much as 400 feet of a 500-foot well may be perforated if the conditions demand it. The type of well described has many advantages in addition to that of rendering several sources of water simultaneously available, and will doubtless be of great value in many localities in the east when the waters at the different levels are under similar heads.

Approximate Methods of Measuring the Yield of Flowing Wells, by Charles S. Slichter.

In this paper descriptions of simple methods and tables for the approximate field determinations of the yield of artesian wells are given. The tables relating to completely filled pipes, both horizontal and vertical, are reprinted from a private report by J. E. Todd, while those relating to measurement of flows from partially filled horizontal and inclined pipes are new. The only instrument required is a foot rule, and the measurement, which consists in measuring the height of the jet in the case of a vertical pipe or its lateral projection in the case of a horizontal pipe, can be made in a few moments. The results are within about 10 per cent of the actual flow, which error is no greater than the average daily variation of flow due to changes of barometric pressure.

Corrections Necessary in Accurate Determinations of Flow From Vertical Well Casings, from Notes furnished by A. N. Talbot.

This paper deals with certain corrections which it is necessary to apply to the figures of the field tables compiled by J. E. Todd and Charles S. Slichter in those cases where refined measurements of flows from vertical well casings are desired. A simple apparatus for measuring the height of the water jet is illustrated, and a diagram showing by curves the coefficients of discharge is given. It was found that with jets less than a foot in height the actual discharge is from 7½ to 12½ per cent lower than the discharge computed from the tables for 2-inch to 6-inch pipes.

Experiment Relating to Problems of Well Contamination at Quitman, Ga., by S. W. McCallie.

Many of the disastrous epidemics which have visited the towns and cities of this country have been traced to polluted drinking water. The present paper deals with a successful effort made to determine the possibility of pollution of the deep wells at Quitman, Ga., the result of which was to prevent a step that might have had fatal results. In a well drilled in 1903 at Quitman a cavity containing what was regarded as a subterranean stream was encountered, and it was thought that such a stream would afford an admirable method of disposing of the city's sewage. Objections were at once raised, however, on every hand, because of the liability of pollution of wells or springs of the region. To test this possibility 2 tons of salt were put into one of the wells, while samples of water from all other wells and springs in the vicinity were taken at short intervals and analyzed. The results showed that the salt had penetrated the deep wells and demonstrated that the emptying of sewage into the underground stream would have resulted in the pollution of the waters of all the deep wells in town and would possibly have led to a serious epidemic.

The New Artesian Water Supply at Ithaca, N. Y., by Francis L. Whitney.

In this paper Mr. Whitney presents an account of the outbreak of the typhoid epidemic of 1903 and the steps taken by various local bodies to obtain a pure supply. The deep wells sunk in the gravels, sands, and clays in the valley of Cayuga Inlet just above Ithaca are described, and the source and geologic occurrence of the supply are discussed. Records of all of the wells are given, the more important being shown by diagrams. The success of the wells, both as to the quantity and the quality of the water, is of special interest, as like supplies could doubtless be obtained at many points in New York and New England which are similarly situated.

Drilled Wells of the Triassic Area of the Connecticut Valley, by W. H. C. Pynchon.

The paper gives a sketch map and section showing the principal geologic features of the area and describes the character and succession of the eastward-dipping series of sandstones, shales, and interbedded or intruded traps throughout the Triassic area of Massachusetts and Connecticut. The geologic discussion is followed by descriptions of a considerable number of wells, in which several points of interest are emphasized, including the nearly uniform water-bearing character of the sandstones, the high percentage of mineral matter present in all the water, and the general absence of flowing wells.

Triassic Rocks of the Connecticut Valley as a Source of Water Supply, by M. L. Fuller.

In this paper a review is given of the occurrence of waters in Triassic rocks of various types, including conglomerates, sandstones, shales, and traps, and the structure, jointing, and faulting of the rocks and their influence on the underground waters are described. Summaries of the conditions favorable and unfavorable to flowing water are given and a number of important conclusions presented. While all of the Triassic rocks except the traps will usually be found to be water bearing, the conditions, because of the interruption of the beds due to faulting or jointing, will rarely be favorable to flowing wells, and high heads can never be expected. The water will in most instances be found to be highly mineralized, but, except possibly in the shallower wells in crowded cities, will rarely be subject to pollution. Attention is called to the need of keeping accurate records and of thoroughly testing each well; and the question of the proper depth of wells is discussed.

Spring System of the Decaturville Dome, Camden County, Mo., by E. M. Shepard.

In the center of this area is a mass of granite (pegmatite) that has apparently been thrust upward through the surrounding Paleozoic limestones and other rocks, which are thereby tilted away from it in all directions. The dome thus formed is surrounded at a distance of several miles by a line of springs, the channels of which seem to radiate from the center of the dome, from which direction the waters appear to come. Several deep flowing wells in similar situations also derive water from the outward-sloping rocks. Descriptions are given of many of the springs, some of which are of immense size and present many points of interest.

Water Resources of the Fort Ticonderoga Quadrangle, Vermont and New York, by T. Nelson Dale.

In this area, which lies on the line between Vermont and New York, there are several important towns, including Ticonderoga in New York, and Proctor, Brandon, Poultney, and West Rutland in Vermont. The land varies considerably in altitude, ranging from low plains near Lake Champlain to ridges 2,700 feet high, such as the one southwest of West Rutland. In general the region is well watered, having numerous springs and streams. The larger streams have, however, become subject to pollution as the industries and towns along their banks have grown up. The limestones or dolomites of the area would doubtless yield water if penetrated by deep wells, but it would probably be hard and in some cases might be liable to pollution. The sandy portion of the drift yields considerable quantities of water, but the clays near the lake give unsatisfactory supplies.

Water Resources of the Taconic Quadrangle, New York, Massachusetts, and Vermont, by F. B. Taylor.

The center of this area falls almost exactly at the point at which the boundaries of the three States mentioned come together. The area is mountainous except in the western third, although it contains valleys with bottoms as low as 350 feet above sea. The drainage is by the Hoosac River, along which, as well as along its tributaries, there are water powers that are either utilized or available. Practically all the cities and towns in the quadrangle obtain their water supplies from mountain streams, but a large proportion of the rural inhabitants procure their supplies from springs. One important mineral spring, developed at a sanitarium, occurs along a probable fault line.

Water Resources of the Watkins Quadrangle, New York, by Ralph S. Tarr.

The paper gives a general description of the water resources of this region, which includes the cities of Elmira and Ithaca, in the southern portion of the State. Special attention is given to the subject of obtaining artesian supplies from the deep gravel-filled valleys, and the steps taken to obtain pure supplies from such a source at Ithaca after the typhoid epidemic of 1903, are described. A number of analyses are given.

Water Resources of the Central and Southwestern Highlands of New Jersey, by Laurence La Forge.

The region treated in this paper is that part of the Highlands which lies south of Andover and Pompton, including about two-thirds of the Highland area of the State. The population is mainly located in villages and is dependent largely upon manufacturing industries for support. The rocks are principally of granitic types, but some conglomerate and quartzite occurs. Lakes and ponds are numerous in a part of the area and streams are abundant and afford numerous water powers as well as the supply for the Morris Canal, while springs are common and furnish water to a considerable number of towns. The surplus water, of which there is considerable, may in the future become of great importance as a source of supply for the large and rapidly growing urban district near New York. The paper describes the needs of this district and the amount and character of the water and its availability as a source of supply.

Water Resources of the Chambersburg and Mercersburg Quadrangles, Pennsylvania, by George W. Stose.

The Chambersburg and Mercersburg quadrangles are located in the Cumberland Valley, in southern Pennsylvania, and include the two important towns from which they are named. They are crossed by several mountain ridges and by many streams that afford water powers, some of which have already been utilized. Many springs are found in the various rocks, especially in the limestone, some of which have been developed as attractive resorts. The public water supplies are obtained largely from spring-fed mountain streams, and in several instances directly from springs.

Water Resources of the Curwensville, Patton, Ebensburg, and Barnesboro Quadrangles, Pennsylvania, by F. G. Clapp.

These quadrangles are situated near the eastern edge of the bituminous coal field, and lie mostly within the limits of Clearfield and Cambria counties. The region is one of high ridges alternating with valleys. Springs are abundant and, except in towns, constitute the main source of water supply. The once noted Cresson Springs are in the area. Many wells obtain abundant supplies, both from the stream gravel and from the rocks. In some places flowing wells are obtained. More than ten towns are equipped with water systems. The majority obtain their supplies from streams, but several procure water from springs or deep wells.

Water Resources of the Elders Ridge Quadrangle, Pennsylvania, by Ralph W. Stone.

This quadrangle lies in Armstrong and Indiana counties, in the west-central part of the State. In general the surface is moderately hilly and is drained by Kiskiminitas River and other streams that flow westward into Allegheny River. Some present available water powers. The region is distinctly a rural district, without large towns, and springs and shallow wells afford the only source of water supply. The Mahoning and Pittsburg sandstones, which overlie the coals of the same name, are the best water bearers.

Water Resources of the Waynesburg Quadrangle, Pennsylvania, by Ralph W. Stone.

The Waynesburg quadrangle is located in Greene County, in the southwest corner of the State. The topography is uniformly hilly, the crests standing generally not over 500 feet above the valleys. The area is drained eastward into the Monongahela by streams of low grade and small volume, with few if any available water powers. The city of Waynesburg obtains its public water supply from a near-by stream, but the water is frequently highly charged with silt and is generally unsatisfactory. The smaller towns depend on shallow private wells. Some of the rock wells yield good supplies, especially those drawing water from the Waynesburg sandstone. In drilling wells to the rock, however, care must be taken not to penetrate the coal. Springs are numerous but small.

Water Resources of the Accident and Grantsville Quadrangles, Maryland, by G. C. Martin.

The area covered by this paper is located in the "handle," in the extreme western portion of Maryland. The topography is essentially that of a plateau, standing between 2,500 and 3,000 feet, above which rise a number of ridges. It is drained by Youghiogheny, Castleman, and Savage rivers, all of which would afford good water supplies. Springs are numerous, especially along the outcrop of the Greenbrier limestone. The possibilities of artesian waters have not been tested, although bore holes sunk for other purposes have given flowing water. It is probable that such flows would be afforded by each of the three synclines which cross the area.

Water Resources of the Frostburg and Flintstone Quadrangles, Maryland and West Virginia, by G. C. Martin.

These quadrangles lie just east of the Grantsville, mainly in western Maryland. They are crossed by a number of ridges that rise as high as 3,000 feet, between which are valleys of considerably lower level. Through these valleys pass the north and south branches of Potomac River and a number of smaller streams. The smaller streams are unpolluted and generally afford good water. Springs abound in the limestone regions. Artesian water is found in sandstones of Carboniferous age, and it is thought that the Oriskany and Tuscarora sandstones probably carry artesian water in the synclines. A large part of the water supply of Frostburg is obtained from an artesian well, but except at Cumberland, there is otherwise little demand for artesian water.

Water Resources of the Cowee and Pisgah Quadrangles, North Carolina, by Hoyt S. Gale.

The Cowee and Pisgah quadrangles are located in the heart of the Southern Appalachians, in the extreme western part of North Carolina. They are traversed by French Broad River and other streams which present available water power at many points. The whole region abounds with springs, generally of pure water, but a few mineral springs, especially chalybeate, occur. Of these the carbonate springs are usually associated with hornblendic gneiss, while the chalybeate waters are associated with pyrite deposits along faults. Very few wells have been sunk in the area.

Water Resources of the Middlesboro-Harlan Region of Southeastern Kentucky, by George H. Ashley.

This region is in a general way a broad basin lying between two high mountain ridges. The surface is cut by deep ravines separated by sharp crests. The rocks are of the Coal Measure series and yield abundant springs, which form the main source of supply of the scattered inhabitants. Shallow wells are frequently relied upon in the bottom lands. No deep wells have been drilled for water, but flowing water has sometimes been obtained from wells drilled for oil. The public supplies of Middlesboro and Pineville, the two principal towns, are obtained from spring-fed mountain streams. Some available water powers exist.

Summary of the Water Supply of the Ozark Region in Northern Arkansas, by George I. Adams.

This area includes portions of the Boston Mountain belt and the Springfield and Salem uplands, the limits of which are shown in fig. 32. The rocks consist largely of Ordovician dolomites and Carboniferous limestones, the former being confined mainly to the Salem upland. Springs are especially numerous in the Boone limestone and chert and the Ordovician dolomites, but some are also found in the Key sandstone. Some of the springs are of immense size, and many have been developed as resorts.

Notes on the Hydrology of Cuba, by M. L. Fuller.

During the American occupation of Cuba much interest was aroused in the water resources of the island, and special attention was given to the problem of water supplies for the various cities. This paper gives, after a résumé of geology, topography, and drainage, a summary of the natural water resources, including underground streams and springs, accounts of the public water supplies, and descriptions of the wells sunk by the War Department for the various military posts. Among the principal water supplies are those of Habana, Matanzas, Cardenas, Cienfuegos, Guantanamo, and Santiago. Underground water courses in the soft limestone, some of them of considerable size, are everywhere present, and springs are very common in many regions. The waters are generally pure, except for the lime, but mineral waters have been exploited for drinking or bathing purposes at a number of localities. The wells drilled by the War Department were located at a considerable number of scattered points. In general they were successful in obtaining supplies at a moderate depth.

DESCRIPTION OF UNDERFLOW METER USED IN MEASURING THE VELOCITY AND DIRECTION OF MOVEMENT OF UNDERGROUND WATER.

By CHARLES S. SLICHTER.

A brief description of the writer's electrical method of measuring the velocities of underground water was printed in the Engineering News of February 20, 1902, and in Water-Supply and Irrigation Paper No. 67 of the United States Geological Survey. The present account will give a more detailed description of the form of the apparatus.

APPARATUS.

The apparatus used is of two types: (1) direct-reading, or hand apparatus, which requires the personal presence of the operator every hour for reading of instruments, and (2) recording apparatus, which requires attention but once in a day. The arrangement of the test wells and manner of wiring the wells is essentially the same in both forms and will now be described.

TEST WELLS.

The test wells may be common 1¼ or 2 inch drive wells if the soil and water-bearing material are easily penetrated, and if the depths to be reached do not exceed 40 feet. For greater depths and harder materials wells of heavier construction should be used. The test wells put down by the Commission on Additional Water Supply for Greater New York in 1903 are suitable for ordinary conditions in the eastern part of the United States, or in any place where the gravels are not too coarse or too compact. These test wells were made of full-weight standard wrought-iron 2-inch pipe, in lengths of 6 or 7 feet, with long threads (1½-inch) and heavy wrought nipples. The well points were 4-foot standard brass jacket points, No. 60 wire gauze. For wells no deeper than 30 feet, closed-end points were driven, but for deeper work open-end points were used. The test wells were driven in place by use of a ram from 150 to 250 pounds in weight, simultaneously hydraulicking a passage for the pipe with water jet in three-fourth inch standard wash pipe. In fine material there was coupled ahead of the open end well point 3 or 4 feet of pipe carrying a shoe coupling, so that the sand, in running in through the open end of the well, would not rise above the bottom of the screen inside of the finished well.

Mr. Homer Hamlin, of Los Angeles, Cal., has devised a powerful drilling rig run by a gasoline engine, which enables him to sink test wells in the bowlder gravel of that locality. He uses a special double-strength casing with flush joints, which he has been able to sink to great depths with his remarkable drilling machine. He has used the electrical method for determining underflow velocities with great success.

The test wells are grouped as shown in fig. 1.

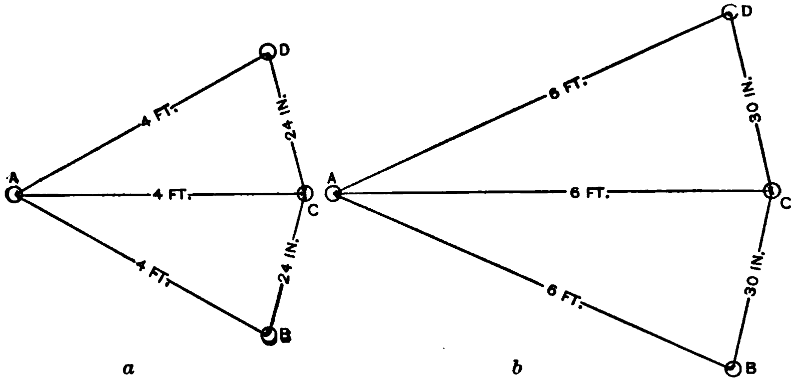
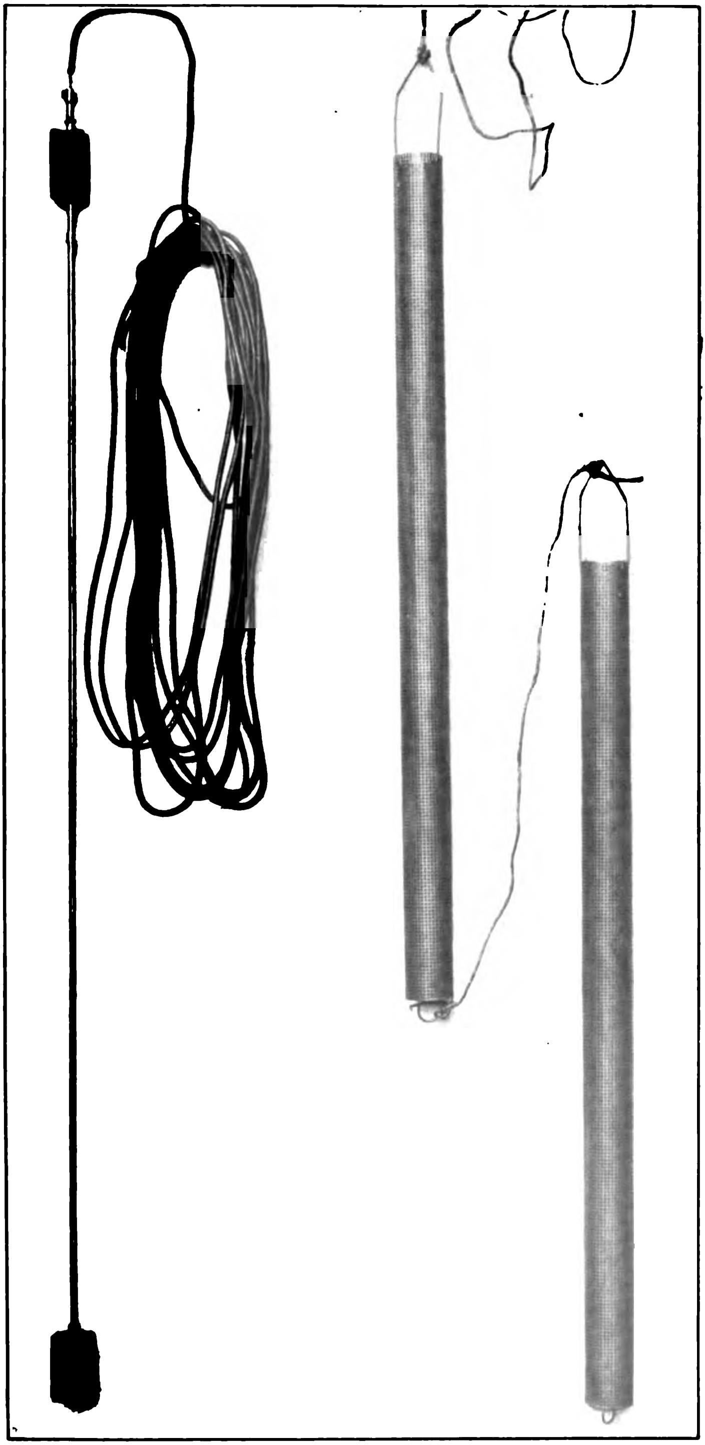


FIG. 1.—Plan of arrangement of test wells used in determining the velocity and direction of motion of ground waters. A, B, C, D are the test wells. The direction A-C is the direction of probable motion of the ground waters. The dimensions given in plan *a* are suitable for depths up to about 25 or 30 feet; those in plan *b* for depths up to about 75 feet. For greater depths the distances A—B, A—C, A—D should be increased to 9 or 10 feet and the distances B—C and C—D to 4 feet. The well A is the "salt well" or well into which the electrolyte is placed.

In case the wells are not driven deeper than 25 feet, an "upstream" or "salt well," A, is located, and three other wells, B, C, and D, are driven at a distance of 4 feet from A, the distance between B and C and C and D being about 2 feet. The well C is located so that the line from A to C will coincide with the probable direction of the ground-water movement. This direction should coincide, of course, with the local slope of the water plane. For deeper work the wells should be placed farther apart, as shown in the right portion of fig. 1. For depths exceeding 75 feet, a radius of 8 or 9 feet and chords of 4 feet should be used, the general requirement being that the wells should be as close together as possible, so as to cut down to a minimum the time required for a single measurement, but not so close that important errors are liable to be introduced by the inability to drive the wells perfectly straight and plumb. On this account the deeper the wells the farther apart they should be placed. The angles B A C and C A D should not exceed 30 degrees.



ELECTRODE AND PERFORATED BRASS BUCKETS USED IN CHARGING WELLS.

METHOD OF WIRING.

Electrical connection is made with the casing of each test well by means of drilled coupling carrying a binding post. Each of the downstream wells, B, C, D, contains within the well point or screen section an electrode consisting of a nickeled brass rod three-eighths inch by 4 feet, insulated from the casing by wooden spools. This electrode communicates with the surface by means of No. 14 rubber-covered copper wire. Fig. 2 illustrates the arrangement of electric circuits between the upstream well and one of the downstream wells. An electrode is shown in Pl. I. At left of cut there is shown an electrode, such as is used in a downstream well. The electrode is 4 feet

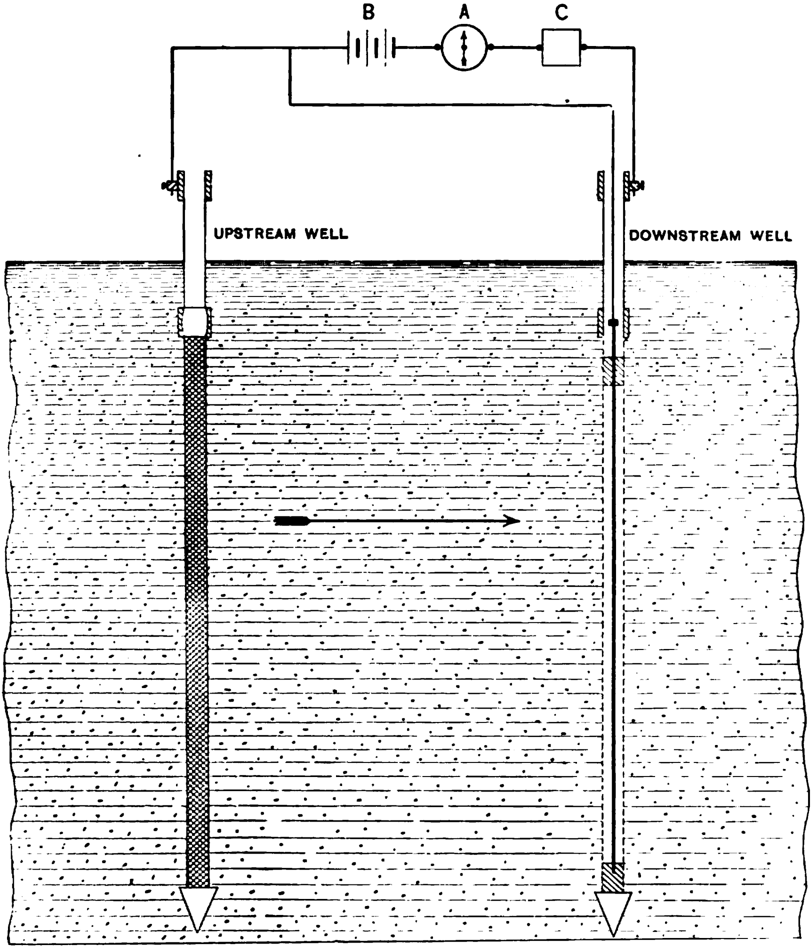


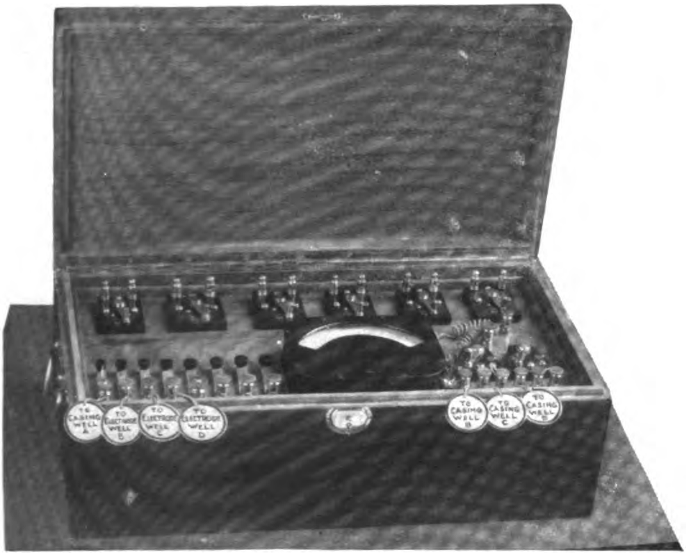
Fig. 2.—Diagram illustrating electrical method of determining the velocity of flow of ground water. The ground water is supposed to be moving in the direction of the arrow. The upstream well is charged with an electrolyte. The gradual motion of the ground water toward the lower well and its final arrival at that well are registered by the ammeter A. B is the battery and C a commutator clock which is used if A is a recording ammeter.

long, made of three-eighths inch nickeled brass rod. Insulators are of wood. The end of rod receives a No. 14 rubber-covered wire, to which good contact is made by a simple chuck clutch. At right of cut are shown two buckets of perforated brass used in charging wells with granulated sal ammoniac. Size of each is 1¾ by 30 inches. Each of the downstream wells is connected to the upstream well in the manner shown in this figure.

DIRECT-READING METER.

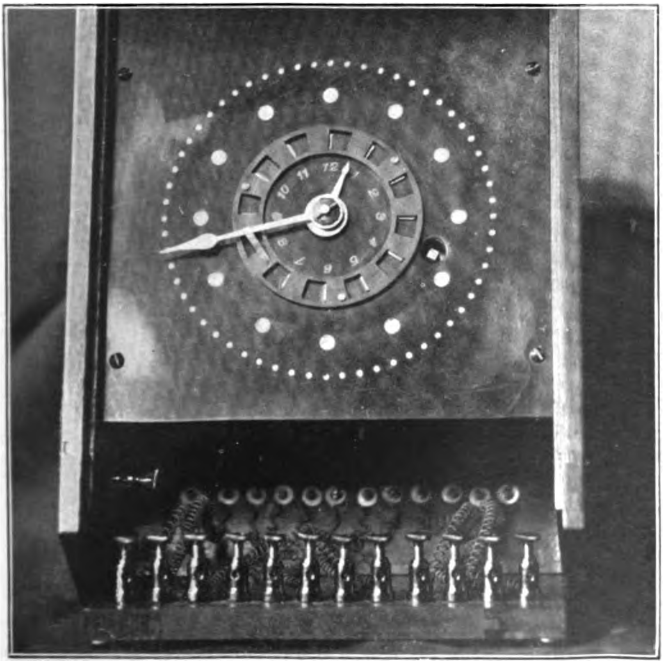
A view of the direct-reading underflow meter is shown in Pl. II, A. Six standard dry cells are contained in the bottom of the box, their poles being connected to the six switches shown at the rear of the case. By means of these switches any number of the six cells may be thrown into the circuit in series. One side of the circuit terminates in eight press keys, shown at the left end of the box. The other side of the circuit passes through an ammeter, shown in the center of the box, to two three-way switches at right end of the box. Four of the binding posts at the left end of the box are connected to the casing of well A and to the three electrodes of wells B, C, and D, in order. The binding posts at the right end of the box are connected to the casings of wells B, C, and D. There are enough binding posts to permit two different groups of wells to be connected with the same instrument. When the three-way switch occupies the position shown in the plate, to press the first key at the left end of box will cause the ammeter to show the amount of current between casing of well A and casing of well B. When the next key is pressed the ammeter will indicate the current between the casing of well B and the electrode contained within it. In the first case the current is conducted between the two well casings by means of the ground water in the soil; in the second case by means of the water within well B. By putting the three-way switch in second position and pressing the first and third keys in turn, similar readings can be had for current between casings A and C, and between casing C and its internal electrode. Similarly, with switch in third position, readings are taken by pressing first and fourth keys. The results may be entered in notebook, as shown in Table I.

The principles involved in the working of the apparatus are very simple. The upstream well A is charged with a strong electrolyte, such as sal ammoniac, which passes downstream with the moving ground water, making the ground water a good conductor of electricity. If the ground water moves in the direction of one of the lower wells, B, C, D, etc., the electric current between A and B, A and C, or A and D will gradually rise, mounting rapidly when the electrolyte begins to touch one of the lower wells. When the electrolyte finally



A. UNDERFLOW METER, SHOWING CONNECTIONS WHEN USED AS DIRECT READING APPARATUS.

The switches at back of case throw any of the dry cells in bottom of box in or out of circuit. When used with recording ammeter, only two connections are made, one to each side of battery circuit; but the ammeter is left in circuit with the recording instrument, to indicate whether the latter is working properly.



B COMMUTATOR CLOCK, FOR USE WITH RECORDING AMMETER.

The clock makes electrical contact at any five-minute interval.

reaches and enters inside of one of the wells B, C, D, it forms a short circuit between the casing of the well and the internal electrode, causing an abrupt rise in the electric current. The result can be easily understood by consulting Table I and fig. 3, in which the current is depicted graphically.

TABLE I.—*Field record of electric current during underflow measurements at station 5, Rio Hondo and San Gabriel River, California, August 5 and 6, 1902.*

[Readings in amperes and decimals of an ampere.]

Time.	Well B.		Well C.		Well D.		Remarks.[a]	
	Casing.	Electrode.	Casing.	Electrode.	Casing.	Electrode.		
8 a. m	0.140	0.360	0.142	0.332	0.150	0.390	....	....
8.15 a. m	Salt.	....	Salt.	....	Salt.	....	1 NaCl	2 NH_4Cl
8.30 a. m	.160	....	.163	....	.170	....	....	1 NH_4Cl
9 a. m	.168	....	.170	....	.180	....	1 NaCl	....
10 a. m	.180	.360	.182	.330	.192	.390	....	1 NH_4Cl
11.40 a. m	.192	.345	.195	.325	.202	.380	....	....
1 p. m	.202	.340	.202	.320	.210	.370	....	1 NH_4Cl
2 p. m	.205	.345	.204	.340	.210	.370	....	....
3 p. m	.208	.342	.205	.320	.210	.360	1 NaCl	....
4 p. m	.210	.350	.205	.320	.210	.370	....	....
5 p. m	.218	.330	.210	.310	.212	.360	....	1 NH_4Cl
6 p. m	.225	.330	.210	.310	.218	.360	....	....
7 p. m	.230	.330	.218	.310	.220	.360	....	....
8 p. m	.240	.330	.222	.310	.223	.350	1 NaCl	....
9 p. m	.250	.330	.222	.320	.225	.352	....	....
10.30 p. m	.275	.340	.225	.315	.225	.360	....	....
12 p. m	.350	.600	.230	.310	.230	.340	....	1 NH_4Cl
1 a. m.[b]	.420	.850	.240	.310	.230	.340	....	....
2.30 a. m	.510	1.550	.240	.310	.230	.340	....	....
4.15 a. m	.560	2.000	.240	.310	.230	.340	....	....
5.30 a. m	.550	2.200	.230	.310	.230	.330	....	....
7.45 a. m	.520	2.250	.230	.310	.225	.330	....	....
8.15 a. m	....	2.250	....	....	....	....	....	....
9 a. m	....	2.200	....	....	....	....	....	....

---

[a] The electrolyte was lowered into well A by means of a perforated brass bucket, 1¾ by 30 inches in size. The formula "2 NH_4Cl" means that two of these buckets, full of ammonium chloride, were introduced into well A at the time indicated. Each of these buckets held 2 pounds of the salt.

[b] August 6.

The time which elapses from the charging of the well A to the arrival of the electrolyte at the lower well gives the time necessary for the ground water to cover the distance between these two wells. Hence, if the distance between the wells be divided by this elapsed time, the result will be the velocity of the ground water. The electrolyte does not appear at one of the downstream wells abruptly; its appearance there is somewhat gradual, as is shown by the curves in figs. 3 and 4. The time required for the electrolyte to reach its maximum strength in one of the downstream wells after its arrival at that well (and, hence, the time required for the current to reach its maximum value) may vary

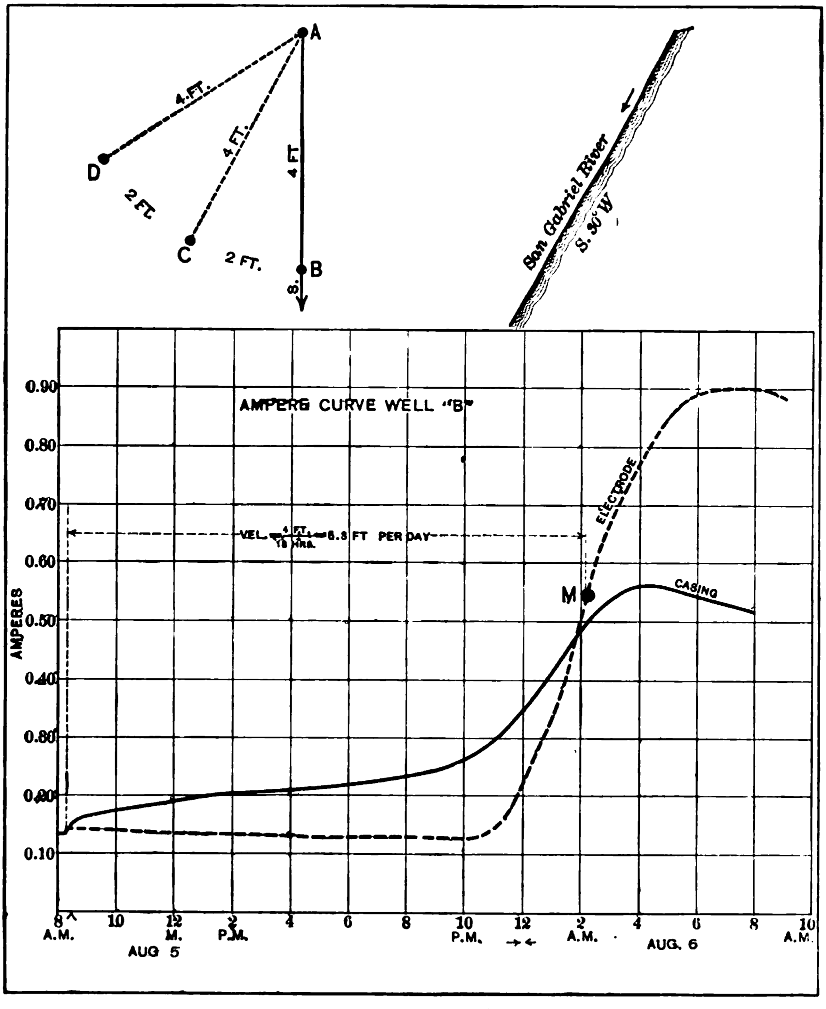


FIG. 3.—Curves showing electric current between casing of well A and casing of well B (heavy curve), and between casing of well B and its internal electrode (dotted curve), at station 5, San Gabriel River, California. These curves illustrate results obtained with the direct-reading form of apparatus.

from a few minutes in a case of high ground water velocity to several hours in a case of low velocity. The writer formerly supposed that the gradual appearance of the electrolyte at the downstream well was largely due to the diffusion of the dissolved salt, but it is now known that diffusion plays but a small part in the result. The principal cause of the phenomenon is the fact that the central thread of water in each capillary pore of the soil moves faster than the water at the walls of the capillary pore, just as the water near the central line of a river channel usually flows faster than the water near the banks. For this reason, if the water of a river be made suddenly muddy at a certain upstream point, the muddiness will appear somewhat gradually at a downstream point, being first brought down by the rapidly moving water in the center of the channel and later by the more slowly moving water near the banks. The effect of the analagous gradual rise in the electrolyte in the downstream well requires us to select the "point of inflection" of the curve of electric current as the proper point to determine the true time at which the arrival of the electrolyte should be counted. This point is designated by the letter M in figs. 3 and 4.

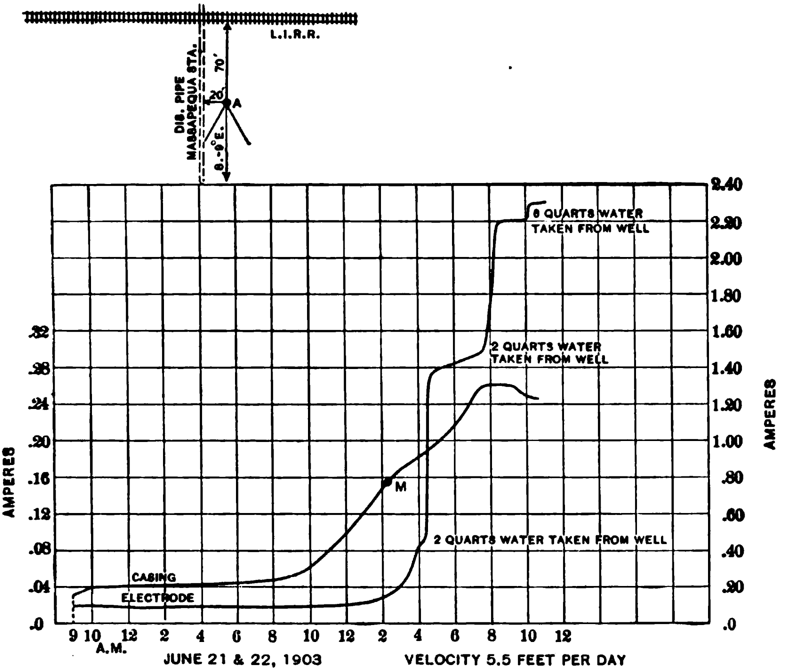


FIG. 4.—Curves showing possibility of use of direct-reading apparatus when well points are not used. The casing in this instance consisted of common black 2-inch pipe, with a few small holes in bottom section. The "casing" curve must be relied upon for determining velocity. The "electrode" curve was obtained by drawing water from well C, as shown on diagram, the charged water being drawn into the well through the small holes and the open end of well.

Owing to the repeated branching and subdivision of the capillary pores around grains of sand or gravel the stream of electrolyte issuing from the well will gradually broaden as it passes downstream. The actual width of this charged water varies somewhat with the velocity of the ground water, but in no case is the rate of the divergence very great. Figs. 5 and 6 show some actual determination of the spread of the electrolyte around a well in a coarse sand, in one case the ground water moving 12 feet a day and in the other case moving 23 feet a day.

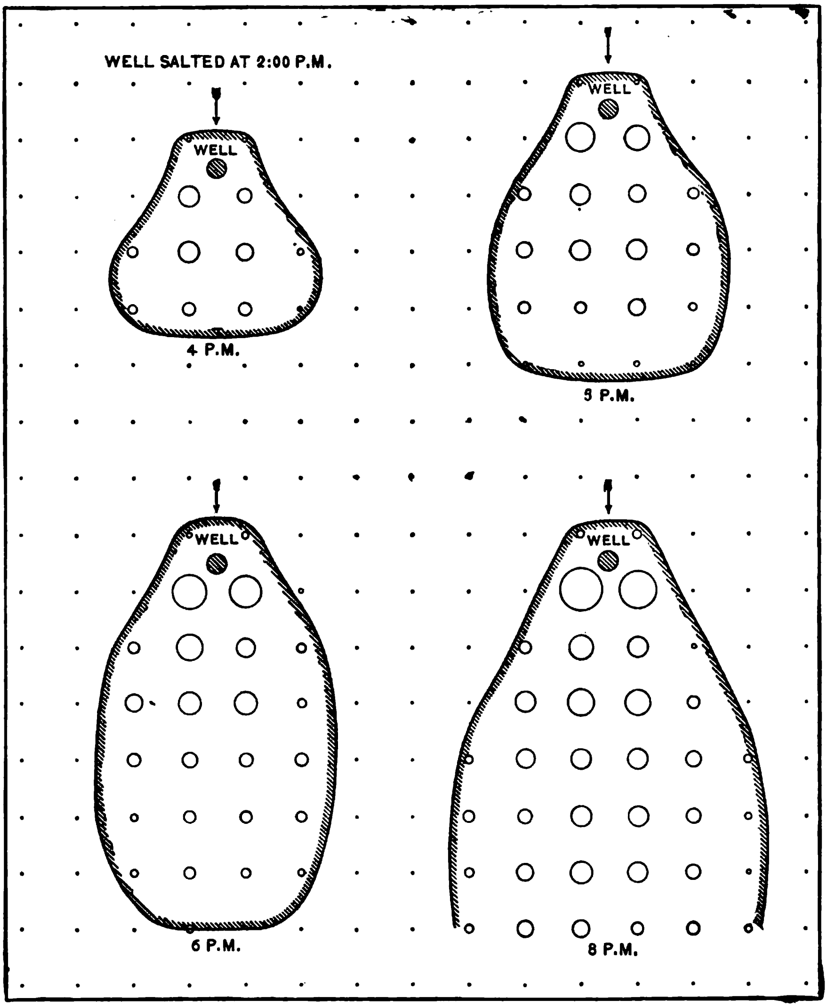


FIG. 5.—Diagram showing the manner in which the electrolyte spreads in passing downstream with the ground water. The shaded circle shows the location of the salted well, and samples were taken from small test wells placed in the sand in rows and columns at intervals of 6 inches, shown by dots in the diagram. The areas of the circles are proportional to the strength of the electrolyte found at their centers. The rough outline indicates the area covered by the charged water at the times specified. The velocity of the ground water (in the direction of the arrows) was 12 feet a day. It can be seen that the electrolyte barely reached a distance of 3 inches against the direction of flow.

Samples of ground water were taken from small test wells placed only 6 inches apart, and the amount of salt or electrolyte was determined chemically. The amount at any point is indicated by the area of the circles shown in the diagrams. It will be seen that the salt barely showed itself at a distance of 3 inches upstream from the well. Three feet downstream from the well the width of the salt stream was about 3 feet in the first case and about 2 feet in the other.

It is possible to dispense with the circuit between the casing of well A to the casing of each of the other wells, as the short circuit between the well and electrode forms the best possible indication of the arrival of the electrolyte at the downstream well. For cases in which the velocity of ground water is high the circuit to well A is practically of no value, but for slow motions this circuit shows a rising current before the arrival of the electrolyte at the lower well, often giving indications that are of much value to the observer.

The method can be used successfully even if only common pipe be used for the wells. In this case, however, the absence of screen or perforations in the wells renders the internal electrodes useless, and one must depend upon the circuit from the well casing of the upstream well to the well casing of the downstream well. The results in Table II and fig. 4 present such a case.

TABLE II.—*Field record of electric current obtained at station 1, Massapequa, Long Island, June 21, 1903, with direct-reading underflow meter.*

[Readings in amperes and decimals of an ampere.]

Time.	Well B.		Well C.		Well D.	
	Casing.	Electrode.	Casing.	Electrode.	Casing.	Electrode.
8.45 a. m	0.03	0.08	0.03	0.10	0.03	0.09
9 a. m. [a]						
9.30 a. m. [b]	.04	.08	.04	.095	.036	.088
10 a. m	.04	.079	.039	.092	.036	.088
10.30 a. m	.04	.079	.04	.097	.039	.087
11 a. m	.04	.079	.04	.095	.059	.087
11.30 a. m	.04	.079	.04	.091	.039	.087
12 m	.041	.079	.04	.092	.040	.087
1 p. m	.042	.079	.04	.090	.040	.088
1.30 p. m	.042	.079	.04	.092	.040	.088
2 p. m	.043	.079	.04	.092	.040	.089
2.30 p. m	.043	.078	.041	.094	.040	.088
3 p. m. [b]	.043	.078	.041	.094	.040	.090
3.30 p. m	.043	.078	.040	.094	.041	.090
4 p. m	.043	.078	.042	.094	.041	.090

[a] 10 pounds of sal ammoniac placed in well A.
[b] 2 pounds of sal ammoniac placed in well A.

TABLE II.—*Field record of electric current obtained at station 1, Massapequa, Long Island, June 21, 1903, with direct-reading underflow meter*—Continued.

Time.	Well B.		Well C.		Well D.	
	Casing.	Electrode.	Casing.	Electrode.	Casing.	Electrode.
4.30 p. m	0.043	0.078	0.042	0.095	0.041	0.090
5 p. m	.043	.078	.042	.096	.041	.090
5.30 p. m	.045	.078	.043	.096	.041	.090
6.30 p. m	.045	.078	.043	.097	.042	.091
7 p. m	.045	.078	.046	.099	.041	.091
7.30 p. m. [a]	.045	.078	.046	.099	.041	.090
8 p. m	.045	.080	.048	.099	.042	.093
8.30 p. m	.049	.080	.049	.100	.043	.094
9 p. m	.048	.079	.050	.100	.043	.094
10.30 p. m	.050	.079	.070	.101	.045	.095
12 p. m	.050	.079	.095	.106	.047	.095
1 a. m. [b]	.051	.079	.120	.122	.049	.099
2 a. m	.051	.079	.147	.152	.050	.100
3 a. m. [a]	.050	.079	.168	.195	.050	.100
4 a. m	.053	.079	.178	.430	.050	.100
4.30 a. m	.053	.079	.188	.470	.050	.100
4.40 a. m				[c] 1.3		
5 a. m	.053	.075	.200	1.4	.050	.100
6 a. m			.200	1.4		
7.45 a. m			.260	1.5		
8 a. m	.052	.075	.260	[d] 1.9	.050	[d] .100
8.15 a. m				[d] 2.20		
8.30 a. m				[d] 2.20		
9.15 a. m			.26	2.20	.049	.099
10 a. m	.050	.072		2.20	.049	.099
10 a. m			.25	[e] 2.30		
11 a. m			.245	2.30		
11 a. m				[e] 2.30		

[a] 2 pounds of sal ammoniac placed in well A.
[b] June 22, 1903.
[c] Before this reading some water was taken from well C.
[d] About 2 quarts of water was taken from well C before this reading.
[e] After 6 quarts of water was taken from well C.

In this case the wells were not provided with well points, but did possess a 4-foot length of pipe, provided with four or five holes on opposite sides of the pipe, containing small one-half inch washer screens. These few openings are not sufficient to permit the electrolyte to freely enter the well, so that readings between casings must be relied upon for results. As a matter of fact, enough of the electrolyte did get into the well to give small increased readings, but in order to obtain the electrode readings given in the table, water was removed from the downstream wells by a small bucket holding about 6 ounces, so as to force a quantity of the water surrounding the well into the perforated sections. The notes appended to Table II show times of "bucketing" well C, and comparison with the column headed "well C, electrode" shows the effect on the strength of solution in the well. In cases where good well points are used the ground water charged with the electrolyte finds its way gradually and naturally into the well. The well point should be clean enough to allow as free passage into the well as through the soil itself. Second-hand points used for this purpose may show a marked lag in the entry of the electrolyte.

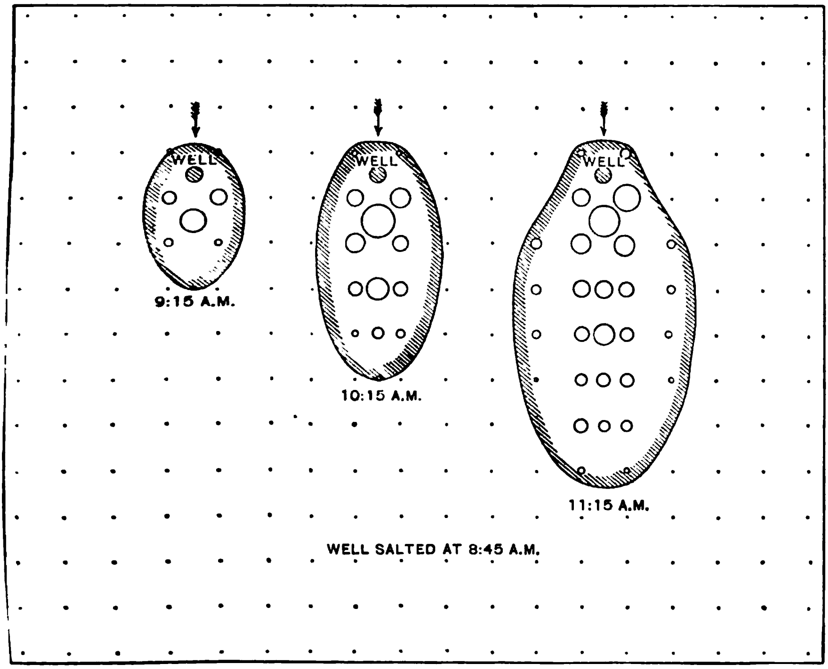


FIG. 6.—Figure showing conditions similar to those shown in fig. 5, but with ground water moving about twice as fast, or 22.9 feet a day. The electrolyte spreads less rapidly for the higher velocities as is seen by comparing this diagram with fig. 5.

Granulated sal ammoniac is used to dose well A. A single charge may vary from 4 to 10 pounds. If common pipe without points or screen is used for the wells, so that internal electrodes must be dispensed with, doses of about 2 pounds each should be repeated about every hour. The dry salt should not be poured directly into the well, but should be lowered in perforated buckets, as shown in Pl. I. These buckets are 1¾ by 30 inches and hold about 2 pounds of the salt. Two of these buckets may be tied one above the other for the initial charge and followed by two more in ten or twenty minutes.

If the wells are not too deep the sal ammoniac may be introduced into the well in the form of a solution. A common bucket full of saturated solution is sufficient. There is an uncertainty in introducing the sal ammoniac in solution in deep wells, as the time required for the solution to sink to the bottom of the well may be considerable.

The ammeter used in the work has two scales, one reading from 0 to 1.5 amperes and the other from 0 to 5 amperes. With a given number of cells the amount of current between the upstream and a downstream well will depend, of course, upon several factors, such as the depth of the wells and their distance apart, but more especially upon the amount of dissolved mineral matter in the ground water. The initial strength of the current can be readily adjusted, however, after

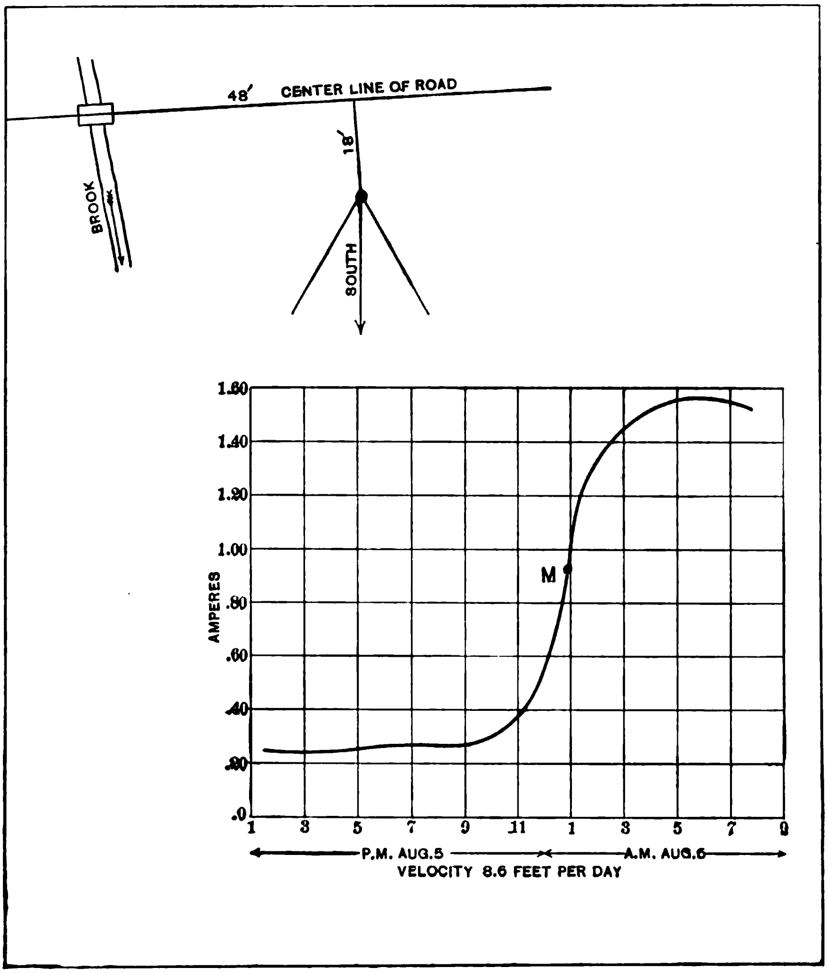
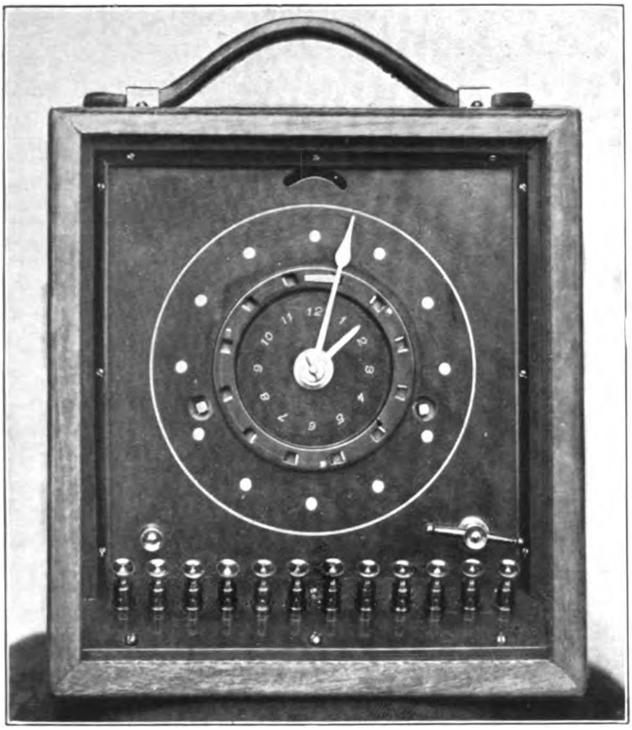
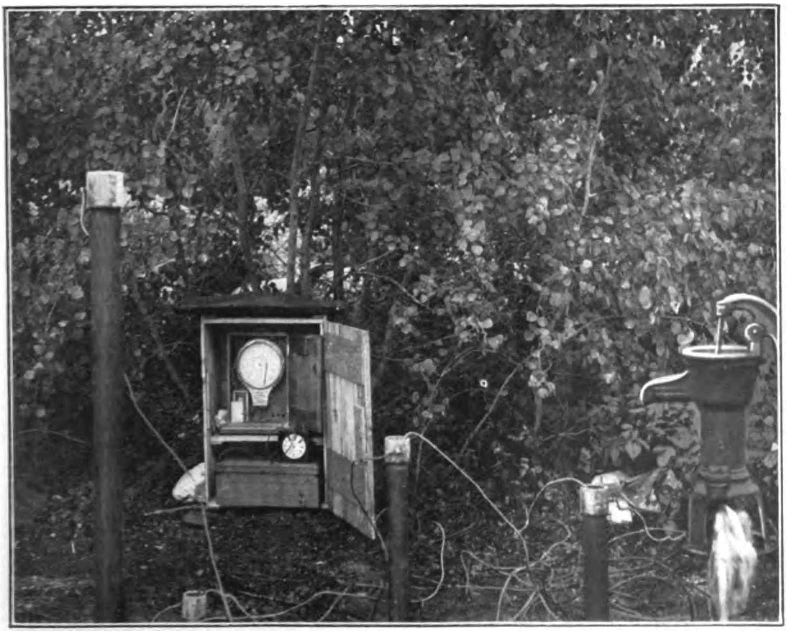


FIG. 7.—Electrical current for well C, station 14, Long Island, plotted on coordinate paper. The record was taken from the chart shown in upper part of fig. 13.



A. COMMUTATOR CLOCK, FOR USE WITH RECORDING AMMETER.

The clock works can be removed for cleaning or oiling without disturbing the rest of the mechanism.



B. RECORDING AMMETER, COMMUTATOR CLOCK, AND BATTERY BOX, IN USE IN THE FIELD.

The instruments are shown as arranged in a rough box 16 by 22 by 36 inches, covered with tar paper.

the wells have been connected with the instruments, by turning on or off some of the battery cells by means of the switches at the rear of the box. It is a good plan to use cells enough to make the initial current between one-tenth and two-tenths of an ampere.

SELF-RECORDING METER.

In the second form of underflow meter self-recording instruments are used, so as to do away with the tedious work of taking the frequent observations, day and night, required when direct-reading instruments are used. The arrangement of the apparatus is not materially different from that described above. In the place of the direct reading ammeter a special recording ammeter is used, having a range of 0 to 2 amperes. It has been found practicable, although it is a

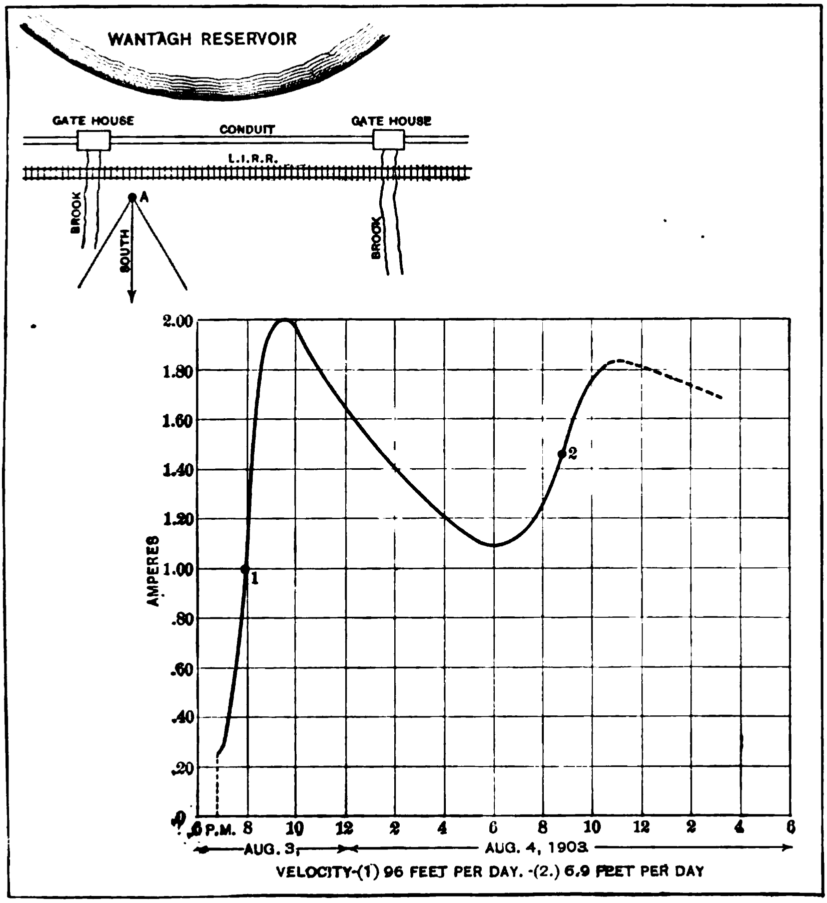


FIG. 8.—Electrical current for well C, station 13, Long Island, plotted on coordinate paper. The record was taken from the chart shown in the lower part of fig. 7. The curve indicates two different velocities in different beds of gravel penetrated by the test wells. One velocity is 96 feet a day; the other 6.9 feet a day.

matter of no small difficulty, to construct an instrument of this low range sufficiently portable for field use and not too delicate for the purpose for which it is intended. The ammeter has a resistance of about 1.6 ohms and is provided with oil dash pot to dampen swing of arm carrying the recording pen. The instruments were manufactured by the Bristol Company. The ammeters have gone through hard usage in the field without breakage or mishap. The portability of the instruments will be materially increased by changes in design which are now being made.

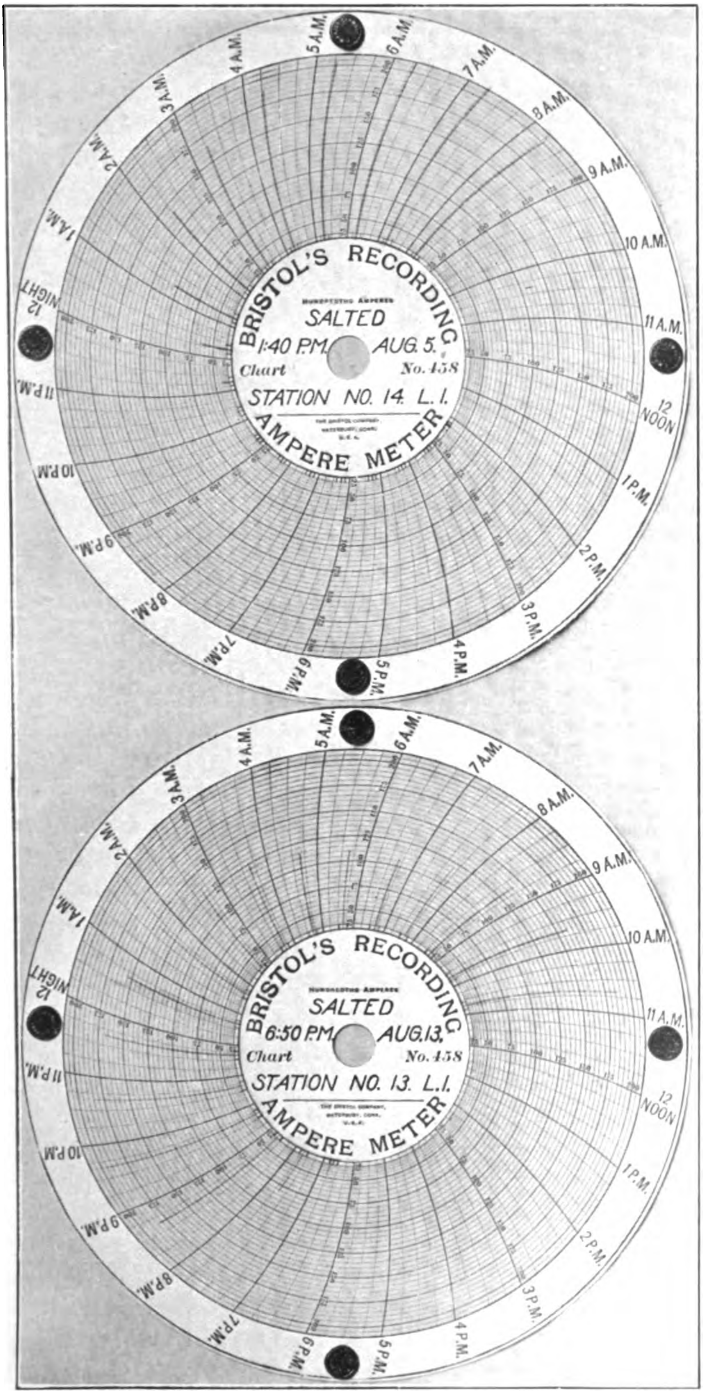
The methods of wiring the wells when the recording instruments are used is slightly changed. In this case one side of the battery circuit is connected to casing of well A and to all of the electrodes of wells B, C, and D. The other side of the battery is run through the recording ammeter to a commutator clock, which once every hour makes a contact and completes the circuit, one after the other, to a series of binding posts. One of these binding posts is connected to the casing of well B, one to the casing of well C, and one to the casing of well D. The time of contact is ten seconds, which gives an abundance of time for the pen to reach its proper position and to properly ink its record.

Pl. II, *B*, and Pl. III, *A*, show two commutator clocks made for this purpose by the instrument maker of the College of Engineering, University of Wisconsin. The clock movement is a standard movement of fair grade, costing about $5. It can readily be taken from the case for cleaning or oiling and replaced. A seven-day marine movement, with powerful springs, is best for this purpose.

It will be seen from the method of wiring the wells that the record will show the sum of the current between well A and well B added to the current between the casing of well B and its electrode. The removal of the connection to well A would permit the record to show the current between the casing of a downstream well and its electrode, but the connection to the upstream well involves no additional trouble, and occasionally its indications are of much service, especially if the velocities are low.

All of the instruments above mentioned can be placed in a common box 16 by 22 by 36 inches, covered with tar paper and locked up. Pl. III, *B*, shows a photograph of the instruments thus arranged. The shelf contains the recording ammeter (shown at left of cut) and the commutator clock (shown at right of cut).

The contacts on the commutator clock are arranged about five minutes apart, so that the record made for the wells will appear on the chart as a group of lines, one for each downstream well, of length corresponding to the strength of the current. The increasing current corresponding to one of the wells will finally be indicated by the lengthening of the record lines for that well. This can be seen by



CHARTS MADE BY RECORDING AMMETER.

consulting the photographs of records shown in Pl. IV. In the upper chart the electrical current for wells B, C, and D at station 14, Long Island, is recorded, in the order named, at 2.10, 2.15, and 2.20 p. m., and hourly thereafter, the current remaining nearly constant at twenty-two to twenty-four hundredths ampere until 10.15 p. m., when the current for well C rises as indicated in the chart. In the lower chart the electrical current for wells B, C, and D is recorded, in the order named, at 6.30, 6.35, and 6.40 p. m., and hourly thereafter. The current for wells B and D remains constant at twenty-five hundredths ampere, but the current for well C is seen to rise as shown in the chart. The record charts are printed in light-green ink, and red ink is used in the recording pen, so that record lines can be readily distinguished when superimposed upon the lines of the chart. A special chart has been designed for this work and is furnished by the Bristol Company as chart 458.

The recording instruments in use have given perfect satisfaction, and the method is a great improvement in accuracy and convenience over the direct-reading method. The highest, as well as the lowest, ground-water velocities yet found have been successfully measured by the recording instruments. By using one or two additional dry cells the instrument may be made quite as sensitive as the direct-reading type.

In using the recording instruments, but a single dose of salt need be placed in the upstream well. If the wells are deep it is important to use enough salt solution to make sure that the salt reaches as far down as the screen of the well point immediately after the solution is poured into the well. A gallon of solution will fill about 6 feet of full weight wrought-iron pipe, so that 10 gallons of solution should be used if the well is 60 feet deep. If the proper amount of solution be not used it will take an appreciable time for the solution to reach the bottom of the well by convection currents, and the results will be vitiated to that extent. As before stated, it is preferable to introduce granulated sal ammoniac into the well in a suitable bucket, in case the depth of the well renders the use of a solution uncertain.

If the ground water runs high in the quantity of total dissolved solids, say more than 100 parts per 100,000 total solids, it is important to run the electric current through the apparatus in a particular direction so as to reduce polarization and lessen the deposit of material upon the electrode. This is accomplished by arranging the batteries so that the positive or carbon pole is connected to the internal electrodes in the downstream wells. The well casings form in this case the negative or other end of the battery circuit, and the available surface is so much greater than it would be if the internal electrodes formed this end of the circuit that little trouble from polarization or falling off of current need be experienced.

THE CALIFORNIA OR "STOVEPIPE" METHOD OF WELL CONSTRUCTION.

By Charles S. Slichter.

INTRODUCTION.

The peculiar conditions of water supply existing in southern California have led to the development of a special type of well which the writer believes to be admirably adapted to conditions found in many places in the eastern part of the United States, especially on Long Island and in the Coastal Plain region of the Atlantic States. It is with the object of calling attention to the importance of this method, by which a large number of water-bearing beds can be drawn upon simultaneously, that the many points of excellence of the California type of wells and methods of well construction are pointed out. In addition to the illustrations accompanying this paper, a number of others showing the rigs, casing, and other appliances used in connection with wells in southern California may be found in the issue of the Engineering News for November 19, 1903.

CONDITIONS IN CALIFORNIA.

The valleys in southern California are filled with deposits of mountain débris, gravels, sands, bowlders, clays, etc., to a depth of several hundred feet, into which a considerable part of the run-off of the mountains sinks. The development of irrigation upon these valleys soon became so extensive that it was necessary to supplement more and more the perennial flow of the canyon streams by ground water drawn from wells in the gravels. This necessity was greatly accentuated by a series of dry years, so that ground waters became a most valuable source of auxiliary supply for irrigation in the important citrus areas in southern California. The type of well that came to the front and developed under these circumstances is locally known as the "stovepipe" well. It seems to suit admirably the conditions prevailing in southern California. In procuring water for irrigation the item of cost is, of course, much more strongly emphasized than in obtaining water for municipal use. The drillers of wells in California were not only confronted with a material which is almost everywhere full of bowlders and similar mountain débris, but also by a high cost of labor and of well casings. It was, undoubtedly, these difficulties that led to the very general adoption in California of the "stovepipe" well.

DESCRIPTION OF APPARATUS AND METHODS.

The wells are put down in the gravel and bowlder mountain outwash or other unconsolidated material to any of the depths common in other localities. One string of casing in favorable location has been put down over 1,300 feet. The usual sizes of casings are 7, 10, 12, and 14 inches, or even larger. A common size is 12 inches. The well casing consists of, first, a riveted sheet-steel "starter," from 15 to 25 feet long, made of two or three thicknesses of No. 10 sheet steel, with a forged steel shoe at lower end. In ground where large bowlders are encountered these starters are made heavier, the shoe 1 inch thick and 12 inches deep, and three-ply instead of two-ply No. 10 sheet-steel body.

The rest of the well casing, above the starter, consists of two thicknesses of No. 12 sheet steel made into riveted lengths, each 2 feet long. One set of sections is made just enough smaller than the other to permit them to telescope together. Each outside section overlaps the inside section 1 foot, so that a smooth surface results both outside and inside of the well when the casing is in place, and so that the break in the joint is always opposite the middle of a 2-foot length. It is these short overlapping sections which are popularly known as "stovepiping."

The casing is sunk by large steam machinery of the usual oil-well type, but with certain very important modifications. In ordinary material the "sand pump" or "sand bucket" is relied upon to loosen and remove the material from the inside of the casing. The casing itself is forced down, length by length, by hydraulic jacks, buried in the ground and anchored to two timbers 14 by 14 inches and 16 feet long, which are planked over and buried in 9 or 10 feet of soil. These jacks press upon the upper sections of the stovepiping by means of a suitable head. The driller, who stands at the front of the rig, has complete control of the engine, the hydraulic pump, and the valves by which pistons are moved up or down, and also of the lever that controls the two clutches which cause tools to work up and down or to be hoisted.

The sand pumps used are usually large and heavy. For 12-inch work they vary in length from 12 to 16 feet, are 10$\frac{3}{8}$ inches in diameter, and weigh, with lower half of jars, from 1,100 to 1,400 pounds.

After the well has been forced to the required depth, a cutting knife is lowered into the well and vertical slits are cut in the casing where desired. A record of material encountered in digging the well is kept and the perforations are made opposite such water-bearing materials as may be most advantageously drawn upon. A well 500 feet deep may have 400 feet of screen, if circumstances justify it.

The perforator (see fig. 9) for slitting stovepipe casing is handled with 3-inch standard pipe with three-fourths-inch standard pipe on the inside. In going down or in coming out of the well the weight of the three-fourths-inch line holds the point of the knife up. When ready to "stick" the three-fourths-inch line is raised. By raising slowly on the 3-inch line with hydraulic jacks, cuts are made from three-eighths to three-fourths inch wide and from 6 to 12 inches long, according to the material at that particular depth. In another type of perforating apparatus (fig. 10) a revolving cutter punches fine holes at each revolution of the wheel. This style of perforator is called a "rolling knife." Besides these many other different kinds of perforators are in use in California. In fact, the perforator is a favorite hobby of the local inventors. They all seem to work well.

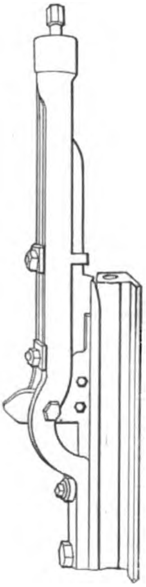


FIG. 9.—Perforator for slitting stovepipe casing.

ADVANTAGES OF CALIFORNIA METHOD.

The advantages of this method of well construction are quite obvious. For wells in unconsolidated material, the California type is undoubtedly the best yet devised. I believe that wells of this type would be highly successful in the unconsolidated coastal deposits on Long Island, in New Jersey, and at similar localities. The absence of bowlders and very coarse gravels in those deposits might possibly make it more advantageous to use the hydraulic jet instead of the ponderous sand bucket in soft material, but this is the only modification that Eastern conditions seem to suggest.

Among the special advantages in the stovepipe construction we may enumerate the following:

1. The absence of screw joints liable to break and give out.

2. The flush outer surface of the casing, without couplings to catch on bowlders or to hang in clay.

3. The elastic character of the casing, permitting it to adjust itself in direction and otherwise to dangerous stresses, to obstacles, etc.

4. The absence of screen or perforation in any part of the casing when first put down, permitting the easy use of sand pump and the penetration of quicksand, etc., without loss of well.

5. The cheapness of large-size casings, because made of riveted sheet steel.

6. The advantage of short sections, permitting use of hydraulic jacks in forcing casing through the ground.

7. The ability to perforate the casing at any level at pleasure is a decided advantage over other construction. Deep wells with much screen may thus be heavily drawn upon with little loss of suction head.

8. The character of the perforations made by the cutting knife are the best possible for the delivery of water and avoidance of clogging. The large side of the perforation is inward, so that the casing is not likely to clog with silt and débris.

9. The large size of casing possible in this system permits a well to be put down in bowlder wash where a common well could not possibly be driven.

10. The uniform pressure produced by the hydraulic jacks is a great advantage in safety and in convenience and speed over any system relying upon driving the casing by a weight or ram.

11. The cost of construction is kept at a minimum by the limited amount of labor required to man the rig, as well as by the good rate of progress possible in what would be considered in many places impossible material to drive in, and by the cheap form of casing.

COST OF THE WELLS.

An idea of the cost of constructing these wells can best be given by quoting actual prices on some recent construction in California. According to contracts recently let near Los Angeles, the cost of 12-inch wells was:

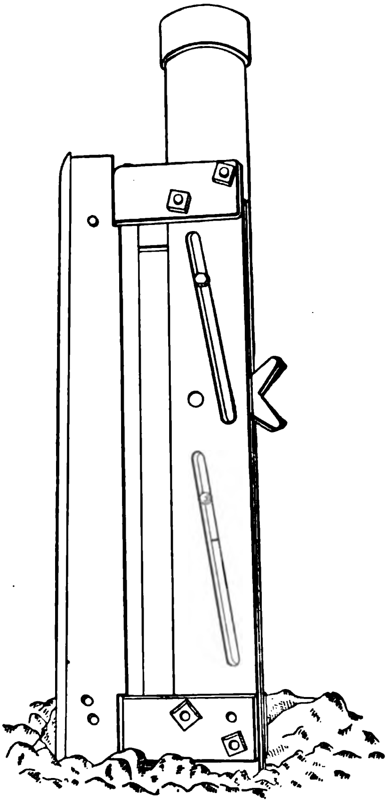


FIG. 10.—Roller type of perforator.

Fifty cents per foot for the first 100 feet, and 25 cents additional per foot for each succeeding 50 feet, casing to be furnished by the well owner. This makes the cost of a 500-foot well $700 in addition to casing. The usual type of No. 12 gauge, double stovepipe casing, is about $1.05 a foot, with $40 for 12-foot starter with three-quarter inch by 8-inch steel ring. A good driller gets $5 a day; helpers, $2.50 a day. The cost of drilling runs higher than that given above in localities where large and numerous bowlders are encountered.

The drillers build their own rigs according to their own ideas, so that no two rigs are exactly alike; that is, the drillers pick out the castings and working parts and mount them according to ideas that experience has taught them are the best for the wash formations in which they must work. Fig. 11 shows a common form of rig.

It is not very profitable to name individual wells of this type and give their flow or yield, since conditions vary so much from place to place. From the method of construction it must be evident that this type of well is designed to give the very maximum yield, as every water-bearing stratum may be drawn upon. The yield from a number of wells in California of average depth of about 250 feet, pumped by centrifugal pumps, varied from about 25 to 150 miners' inches, or from 300,000 to 2,000,000 gallons a day. These are actual measured yields of water supplied for irrigation.

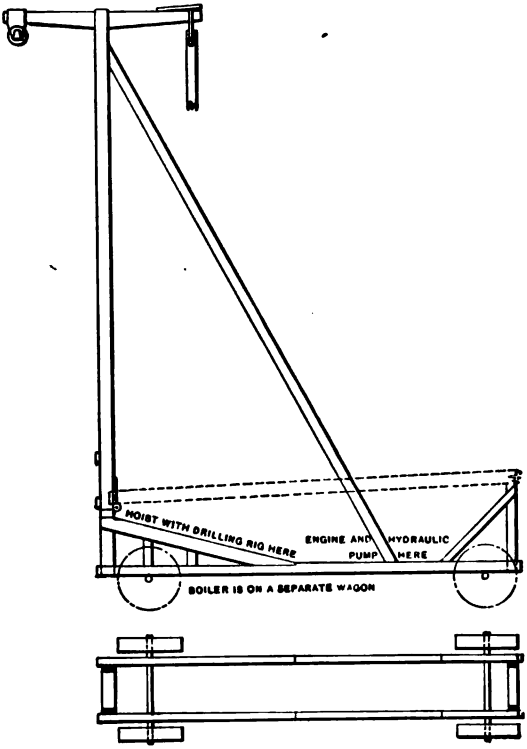


FIG. 11.—Common form of California well rig.

Among the very best flowing wells in southern California are those near Long Beach. The Boughton well, the Bixby wells, and the wells of the Sea Side Water Company are 12-inch wells, varying in depth from 500 to 700 feet and flowing about 250 miners' inches each, or over 3,000,000 gallons per twenty-four hours. The flow of one of these wells is the greatest I have seen reported. Among the records for depth are those of 1,360 feet for a 10-inch well, and 915 feet for a 12-inch well. A new 14-inch well has already reached a depth of 704 feet.

APPROXIMATE METHODS OF MEASURING THE YIELD OF FLOWING WELLS.

By CHARLES S. SLICHTER.

Tables for determining the discharge of water from completely filled vertical and horizontal pipes were prepared a number of years ago by Prof. J. E. Todd, State geologist of South Dakota, who issued a private bulletin describing simple methods of determining quickly, with fair accuracy and with little trouble, the yield of artesian wells. In the following notes the tables and explanations relating to vertical and horizontal pipes are taken from this bulletin. The explanations and tables relating to the measurement in the partially filled horizontal and inclined pipes have been appended by the present writer.

MEASUREMENT OF FLOWS FROM FILLED PIPES.

In determining the flow of water discharged through a pipe of uniform diameter all that is necessary is a foot rule, still air, and care in taking measurements. Two methods are proposed, one for pipes discharging vertically, which is particularly applicable before the well is permanently finished, and one for horizontal discharge, which is the most usual way of finishing a well.

The table on page 39 is adapted to wells of moderate size as well as to large wells. In case the well is of other diameter than given in the table its discharge can without much difficulty be obtained from the table by remembering that, other things being equal, the discharge varies as the square of the diameter of the pipe. If, for example, the pipe is one-half inch in diameter its discharge will be one-fourth of that of a pipe 1 inch in diameter for a stream of the same height. In a similar manner the discharge of a pipe 8 inches in diameter can be obtained by multiplying the discharge of the 4-inch pipe by 4.

In the first method the inside diameter of the pipe should first be measured, then the distance from the end of the pipe to the highest point of the dome of the water above, in a strictly vertical direction—*a* to *b* in the diagram, fig. 12. Find these distances in Table I (A), and the corresponding figure will give the number of gallons discharged each minute. Wind would not interfere in this case, so long as the measurements are taken vertically.

The method for determining the discharge of horizontal pipes requires a little more care. First, measure the diameter of the pipe, as before, then the vertical distance from the center of the opening of the pipe, or some convenient point corresponding to it on the side of the pipe, vertically downward 6 inches, *a* to *b* of the diagram, then from this point strictly horizontally to the center of the stream, *b* to *e*. With these data the flow in gallons per minute can be obtained from Table I (B). It will readily be seen that a slight error may make much difference in the discharge. Care must be taken to measure horizontally and also to the center of the stream. Because of this difficulty it is desirable to check the first determination by a second. For this purpose columns are given in the tables for corresponding measurements 12 inches below the center of the pipe. Of course the discharge from the same pipe should be the same in the two measurements of the same stream. Wind blowing either with or against the water may vitiate results to an indefinite amount; therefore measurements should be taken while the air is still.

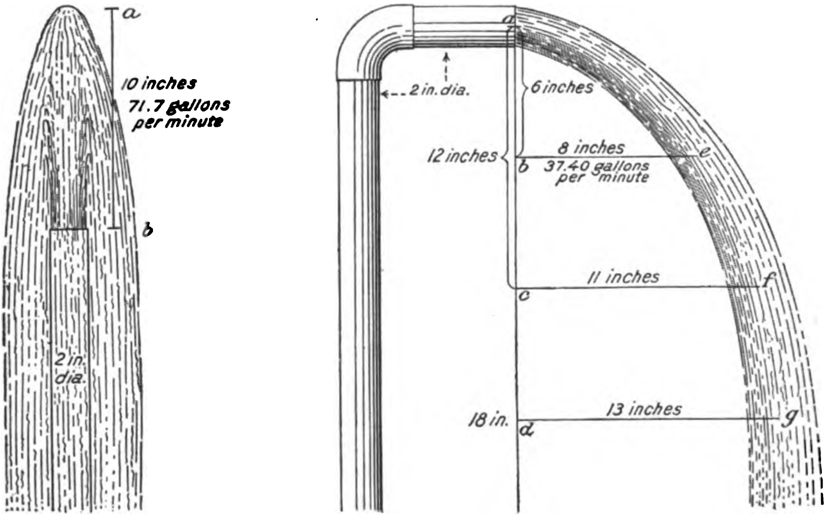


FIG. 12.—Diagram illustrating flow from vertical and horizontal pipes.

Whenever fractions occur in the height or horizontal distance of the stream, the number of gallons can be obtained by apportioning the difference between the readings in the table for the nearest whole numbers, according to the size of the fraction. For example, if the distance from the top of the pipe to the top of the stream in the first case is 9⅓ inches, one-third of the difference between the reading in the table for 9 and 10 inches must be added to the former to give the correct result.

In case one measures the flow of a well by both methods he may think that the results should agree, but such is not the case. In the vertical discharge, there being less friction, the flow will be larger; so also in the second method differences will be found according to the length of the horizontal pipe used.

As pipes are occasionally at an angle, it is well to know that the second method can be applied to them if the first measurement is taken strictly vertically from the center of the opening, and the second measurement from that point parallel with the axis of the pipe to the center of the stream, as before. The measurements can then be read from the table.

TABLE I.—*For determining yield of artesian wells.*

[In gallons per minute.]

A. Flow from vertical pipes.						B. Flow from horizontal pipes.				
Height of jet.	Diameter of pipe in inches.					Horizontal length of jet.	1-inch pipe.		2-inch pipe.	
	1	1¼	1½	2	3		6-inch level.	12-inch level.	6-inch level.	12-inch level.
Ins.						*Ins.*				
½	3.96	6.2	8.91	15.8	35.6	6	7.01	4.95	27.71	19.63
1	5.60	8.7	12.6	22.4	51.4	7	8.18	5.77	32.33	22.90
2	7.99	12.5	18.0	32.0	71.9	8	9.35	6.60	36.94	26.18
3	9.81	15.3	22.1	39.2	88.3	9	10.51	7.42	41.56	29.45
4	11.33	17.7	25.5	45.3	102.0	10	11.68	8.25	46.18	32.72
5	12.68	19.8	28.5	50.7	113.8	11	12.85	9.08	50.80	35.99
6	13.88	21.7	31.2	55.5	124.9	12	14.02	9.91	55.42	39.26
7	14.96	23.6	33.7	59.8	134.9	13	15.19	10.73	60.03	42.54
8	16.00	25.1	36.0	64.0	144.1	14	16.36	11.56	64.65	45.81
9	17.01	26.6	38.3	68.0	153.1	15	17.53	12.38	69.27	49.08
10	17.93	28.1	40.3	71.6	161.3	16	18.70	13.21	73.89	52.35
11	18.80	29.5	42.3	75.2	169.3	17	19.87	14.04	78.51	55.62
12	19.65	30.7	44.2	78.6	176.9	18	21.04	14.86	83.12	58.90
13	20.46	31.8	45.9	81.8	184.1	19	22.21	15.69	87.74	62.17
14	21.22	33.0	47.6	84.9	190.9	20	23.37	16.51	92.36	65.44
15	21.95	34.2	49.3	87.8	197.5	21	24.54	17.34	96.98	68.71
16	22.67	35.2	50.9	90.7	203.9	22	25.71	18.17	101.60	71.98
17	23.37	36.3	52.5	93.5	210.3	23	26.88	18.99	106.21	75.26
18	24.06	37.5	54.1	96.2	216.5	24	28.04	19.82	110.83	78.53
19	24.72	38.6	55.6	98.9	222.5	25	29.11	20.64	115.45	81.80
20	25.37	39.6	57.0	101.6	228.5	26	30.38	21.47	120.07	85.07
21	26.02	40.6	58.4	104.2	234.3	27	31.55	22.29	124.69	88.34
22	26.66	41.6	59.9	106.7	240.0	28	32.72	23.12	129.30	91.62
23	27.28	42.6	61.4	109.2	245.6	29	33.89	23.95	133.92	94.89
24	27.90	43.5	62.8	111.6	251.1	30	35.06	24.77	138.54	98.16
25	28.49	44.4	64.1	114.0	256.4	31	36.23	25.59	143.16	101.43
26	29.05	45.3	65.3	116.2	261.4	32	37.40	26.42	147.78	104.70

TABLE I.—*For determining yield of artesian wells*—Continued.

A. Flow from vertical pipes.						B. Flow from horizontal pipes.				
Height of jet.	Diameter of pipe in inches.					Horizontal length of jet.	1-inch pipe.		2-inch pipe.	
	1	1¼	1½	2	3		6-inch level.	12-inch level.	6-inch level.	12-inch level.
Ins.						*Ins.*				
27	29.59	46.1	66.4	118.2	266.1	33	38.57	27.25	152.39	107.98
28	30.08	46.9	67.5	120.3	270.4	34	39.64	28.08	157.01	111.25
29	30.55	47.5	68.5	121.9	274.1	35	40.45	28.64	161.63	114.52
30	30.94	48.2	69.4	123.4	277.6	36	41.60	29.46	166.25	117.79
36	34.1	53.2	76.7	136.3	306.6					
48	39.1	61.0	88.0	156.5	352.1					
60	43.8	68.4	98.6	175.2	394.3					
72	48.2	75.2	108.0	192.9	434.0					
84	51.9	81.0	116.8	207.6	467.0	Continue by adding for each inch—				
96	55.6	86.7	125.0	222.2	500.0					
108	58.9	92.0	132.6	235.9	530.8					
120	62.2	98.0	139.9	248.7	559.5					
132	65.1	102.6	146.5	260.4	585.9		1.15	0.82	4.62	3.27
144	68.0	106.4	153.1	272.2	612.5					

NOTE.—To convert results into cubic feet, divide the number of gallons by 7.5, or, more accurately, by 7.48.

The flow in pipes of diameters not given in the table can easily be obtained in the following manner:

For ½-inch pipe, multiply discharge of 1-inch pipe by	0.25
For ¾-inch pipe, multiply discharge of 1-inch pipe by	0.56
For 1¼-inch pipe, multiply discharge of 1-inch pipe by	1.56
For 1½-inch pipe, multiply discharge of 1-inch pipe by	2.25
For 3-inch pipe, multiply discharge of 2-inch pipe by	2.25
For 4-inch pipe, multiply discharge of 2-inch pipe by	4.00
For 4½-inch pipe, multiply discharge of 2-inch pipe by	5.06
For 5-inch pipe, multiply discharge of 2-inch pipe by	6.25
For 6-inch pipe, multiply discharge of 2-inch pipe by	9.00
For 8-inch pipe, multiply discharge of 2-inch pipe by	16.00

MEASUREMENT OF FLOWS FROM PARTLY FILLED PIPES.

From Table II, given below, it should be possible, if the wind is not blowing too hard, to determine the flow with an error probably not exceeding 10 per cent. This error is no greater than the fluctuation of the flow due to the daily variations of the barometric pressure in the case of most wells. The results in extreme cases, such as a one-fourth inch stream in a 6-inch pipe, are, of course, still less accurate, and actual measurement by collecting the water in a vessel of definite capacity should be resorted to if possible.

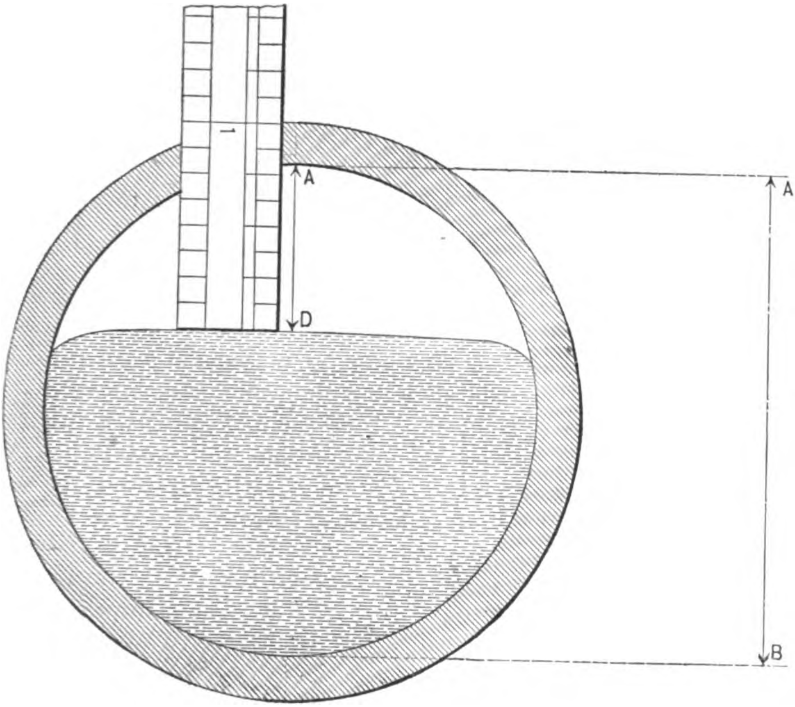


FIG. 13.—Method of measuring partly filled pipes.

TABLE II.—*For estimating the discharge from partly filled horizontal or sloping pipes.*

Fractional part of diameter of pipe not occupied by water. [Obtained by dividing A D by A B in fig. 1.]	Discharge expressed as percentage of discharge from full pipe, same size.	Fractional part of diameter of pipe not occupied by water. [Obtained by dividing A D by A B in fig. 1.]	Discharge expressed as percentage of discharge from full pipe, same size.
0.05	0.98	0.55	0.44
.10	.95	.60	.37
.15	.91	.65	.31
.20	.86	.70	.25
.25	.80	.75	.20
.30	.75	.80	.14
.35	.69	.85	.092
.40	.63	.90	.054
.45	.55	.95	.015
.50	.50	1.00	.000

To estimate discharge from partly filled horizontal or sloping pipe, first estimate discharge from full pipe of same size by means of Table I.

Next measure with a foot rule the dimension A D (see fig. 13) of the empty portion of cross section of the pipe. Divide this by the inside diameter of the pipe, which will give the fractional part of the diameter that is occupied by the empty part of pipe. In Table II find in the first column the number nearest to the above quotient. Opposite this number will be found the per cent of discharge of full pipe which the partially filled pipe is yielding. It is sufficient to measure the distance A D to the nearest eighth of an inch, or at most to the nearest sixteenth of an inch.

EXAMPLE.

Suppose that a 2-inch horizontal pipe has a length of jet of 13 inches at 6-inch level. From Table I this would represent a discharge of 60 gallons per minute from full pipe. Suppose that the distance A D is five-eighths of an inch and A B is 2 inches, or sixteen-eighths of an inch. Dividing 5 by 16 gives 0.31. In the first column of Table II we find 0.30, the nearest to 0.31, and opposite 0.30 in the second column of the table appears 0.75. The discharge from the partly filled pipe is therefore 60×0.75=45 gallons per minute.

CORRECTIONS NECESSARY IN ACCURATE DETERMINATIONS OF FLOW FROM VERTICAL WELL CASINGS.

From notes furnished by A. N. TALBOT.

The method described by Professor Todd is based on certain assumed theoretical conditions. While the error resulting from the method of measurement is usually less than 10 per cent, and while it is of great value in approximate field determinations, certain corrections must be made in order to exactly determine the amount of flow.

The considerations to be taken into account are that in vertical pipes the water will not rise to the height of its full velocity head and that the velocity is not uniformly distributed over the cross section. For velocity heads equal to the diameter of the pipe up to a height of 10 feet this discrepancy is not very great, but for lower values it is considerable. Fig. 15 shows the coefficients for 2-inch, 4-inch, and 6-inch pipes from low heads up to heads of 2 to 3 feet. These range from 0.80 to 0.96. The values above this, until atmospheric resistance becomes great, will not be much different. The quantities found by Professor Todd's table should be multiplied by these coefficients. These values

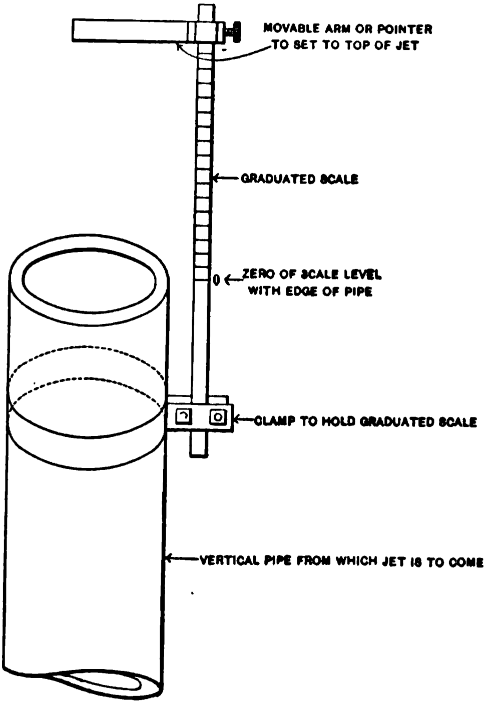

MOVABLE ARM OR POINTER TO SET TO TOP OF JET
GRADUATED SCALE
0
ZERO OF SCALE LEVEL WITH EDGE OF PIPE
CLAMP TO HOLD GRADUATED SCALE
VERTICAL PIPE FROM WHICH JET IS TO COME

FIG. 14.—Sketch showing application of movable pointer and scale in measuring jets.

are fixed on the assumption that the height of water may be determined by finding the distance from the end of the pipe to the highest point

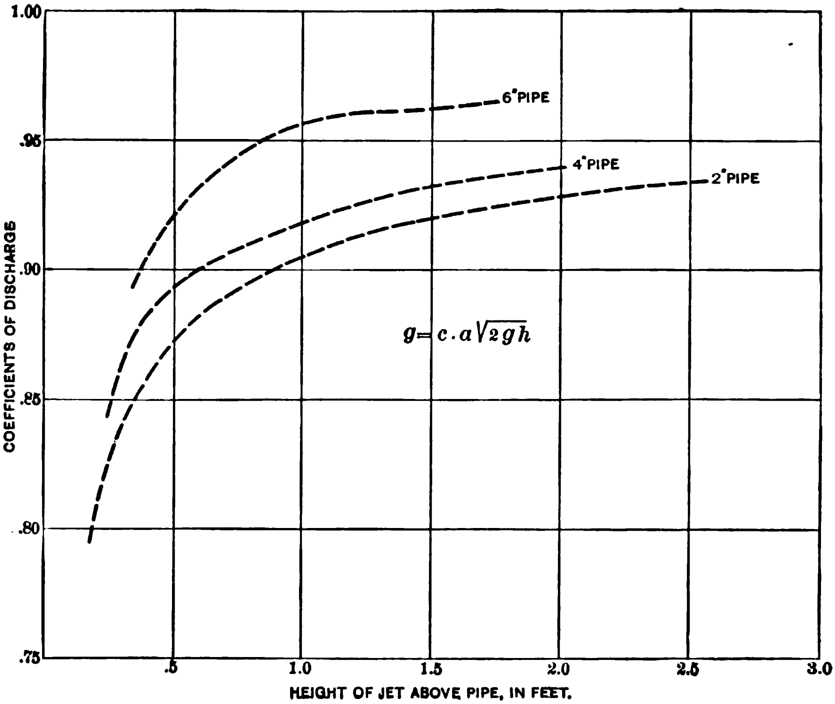


FIG. 15.—Coefficients of discharge for high and low heads.

of the jet by means of a movable pointer and scale, as shown in fig. 14, or by some similar device.

EXPERIMENT RELATING TO PROBLEMS OF WELL CONTAMINATION AT QUITMAN, GA.

By S. W. McCallie.

INTRODUCTION.

During the summer of 1903, a boring for a deep well, constructed by the town of Quitman, Ga., to improve its water supply, penetrated, at a depth of 123 feet from the surface, in limestone, what appeared to be a cavity 6¾ feet deep. Immediately after the cavity had been penetrated by the drill the water rose to within 77 feet of the surface, at which point it remained. In extending the bore hole beyond this depth it was found that all of the water forced into the well to carry out the drillings, and also the drillings themselves, appeared to pass off by the cavity. It was further discovered that any quantity of water, however great, that was forced into the bore hole, did not raise the level of the water in the well above 77 feet, and, on the other hand, that continuous pumping was equally ineffective in lowering the level.

After the sinking of the well to a second water-bearing stratum, at a depth of 321 feet, another well was constructed with a view of testing more fully the water-carrying capacity of the underground cavity, which was supposed to be a channel of a large subterranean stream. The second well, 6 inches in diameter, was put down a few hundred yards southwest of the first well, and only a few feet from the margin of Russell Pond, a small body of stagnant water occupying a nearly circular depression having the appearance of a partially filled lime sink. This well having been extended to the cavernous limestone, a canal was dug to connect it with the pond, and the water was allowed to flow from the pond into the well. The pond, which contained about one-half million gallons of water, was drained by the well in a few hours, without apparently affecting the level of the water in the bore hole, which remained constant at 77 feet from the surface. This test was conclusive to the town authorities that the underground cavity had a capacity to carry off an illimitable amount of water, and it was at once suggested that the town might be able to make use of this so-called underground stream for sewage disposal. This suggestion was soon taken up by the press of south Georgia, and within a short time Governor Terrell received a number of letters importuning him to interfere to prevent the Quitman authorities from using deep wells for sewerage purposes.

At the request of the governor, the writer, who at that time was engaged in the study of the underground waters of Georgia for the State and the United States Geological Survey, made a trip to Quitman to investigate the reports and, if they should be found true, to point out to the people of Quitman the possibility that such a sewerage system might contaminate the wells and springs in that region. When the writer arrived at Quitman he found that the town authorities were seriously considering the question of disposing of the sewage as reported. They were willing, however, to give up the idea of using the supposed underground stream for sewerage purposes if it could be shown that such use would prove injurious in any way whatever. Furthermore, they were willing to cooperate with the State and the United States surveys by paying the greater part of the expense of any experiments that might be necessary to establish this fact.

After some delay arrangements were finally made with the United States Geological Survey for conducting an experiment to determine the possibility of contamination of adjacent wells and springs, the plan adopted for this purpose being what is known as the chlorine method of tracing underground watercourses.

The well into which the chlorine (sodium chloride) was introduced in carrying out this experiment was the Russell Pond well, referred to above. The well has a depth of 120 feet, and shows the following section:

Section of well at Russell Pond, near Quitman, Ga.

	Feet.
1. Surface sand	2
2. Varicolored clay	60
3. Yellow sand	15
4. Gray sandy clay	43
5. Limestone (water bearing).	

The water, which rises to about 77 feet of the surface, comes from the cavernous limestone found in all of the deep wells of Quitman and vicinity.

GEOGRAPHY AND GEOLOGY.

Before the experiment is described in detail a few general notes will be given on the geography and geology of the region, both of which have a certain bearing on the question under consideration.

That part of south Georgia covered in conducting the Quitman experiment lies along the Georgia-Florida State line, and includes the southern part of Brooks and the adjacent portions of Thomas and Lowndes counties. This part of the State is comparatively level, but in parts of Brooks County the surface is more or less rolling, and depressions caused by lime sinks are occasionally seen. The streams, which all flow southward, are usually sluggish, and at points in their course frequently traverse cypress swamps of considerable extent.

The springs of the region are few in number, but are usually large. They are generally found in or near the larger streams, and are often submerged during the wet season.

The geology of the region is typical of the portion of south Georgia that lies along the State line west of Thomasville, and that has been described by Spencer and others. Nearly everywhere throughout the piny woods or the cultivated fields of this section is to be seen a superficial covering or veneer of fine sand, which at some points attains a thickness of 2 feet or more. This sand corresponds probably to McGee's Columbia formation, as it lies directly upon the orange and reddish Lafayette clays.

The Lafayette clays, which are well exposed in numerous cuts along the Coast Line Railroad both east and west of Quitman, are usually stratified below and massive above. On the more elevated lands they attain a thickness of many feet, but along the larger streams they have been partially or wholly removed by erosion so as to expose underlying clays which at certain points along Withlacoochee River, notably at McIntyre Spring, contain large masses of coral. These lower clays are probably Miocene, and belong, no doubt, to Langdon's Chattahoochee group.

Beneath these Miocene clays there is a thick limestone, which is the source of the water supply of all the deep wells at Quitman, Boston, and Valdosta. This limestone seems to belong to Conrad's Vicksburg group, which, according to Dall, forms the lowest member of the Oligocene beds in the southern Tertiary series. As is shown by samples of borings from deep wells, this rock is somewhat variable in character, but seems to consist largely of thick beds of comminuted shells and corals interlaminated with layers of hard, compact limestone. The upper beds of this limestone appear to be cavernous, for cavities, shown by the dropping of the drill, are frequently found in it in the deep wells throughout the region. These cavities are said to vary in depth from 3 to 9 feet, and are always filled with water having a static head that is 40 feet or more higher than the point at which the cavities are struck.

The order of occurrence and the approximate thickness of these several formations are shown in the section of the Russell Pond well, above given. The Boston and the Quitman wells also show similar sections. The dip of the formations is supposed to be toward the south at a few feet per mile.

DESCRIPTION OF EXPERIMENT.

The chlorine method of tracing underground streams, as carried out in the Quitman experiment, was adopted at the suggestion of Prof. C. S. Slichter, consulting engineer of the United States Geological Survey.

A reconnaissance topographic survey of the region surrounding Quitman was made, with the view of finding all springs and wells whose waters stood at a lower level than the water in the Russell Pond well, where the salt was to be introduced, altitudes being determined by aneroid barometer. From all such springs samples of water were collected for determination of the amount of chlorine present. Each of the springs and wells thus sampled was made a station from which, at regular intervals, samples of water were collected by observers who were advised how and when to collect samples. The various stations having been established and samples collected for the determination of the normal amount of chlorine contained in the waters, 2 tons of salt (sodium chloride) were introduced into the Russell Pond well. The salt was put into the well in the form of solution, its introduction beginning at 8 a. m. October 15, and continuing until 8 p. m. October 20. The first ton of salt put into the well was introduced continuously for twelve hours at the rate of 166⅔ pounds an hour, while the second ton was put into the well continuously for one hundred and twenty hours, or five days, at the rate of 16⅔ pounds an hour.

In order to introduce the salt into the well at the above rate and also to insure as complete saturation of the water as possible, five 50-gallon barrels were set about 20 inches apart upon a level platform at the well and connected with one another by pieces of 2-inch iron pipe, firmly screwed into the barrels by right and left screws cut on their opposite ends. The iron pipe was inserted into the barrel nearest the well about 2 inches from the bottom, while the pipe between each succeeding barrel was elevated about 4 inches, so that the one uniting the last two barrels entered them about halfway up. When everything was in readiness for the experiment to begin, each barrel was filled with salt up to the point at which the outflow pipe entered it. The water was then turned into the barrel farthest from the well through a hydrant connected with the public water supply. As the water rose in this barrel to the point of entrance of the pipe it flowed into the next barrel, and so on until the entire chain of barrels was filled. The water now being more or less completely saturated, having flowed over the salt in the bottom of each barrel, was turned into the well through a stopcock so adjusted as to deliver the desired amount of water per minute. By a nice adjustment of the stopcock at the well and of that at the hydrant it was found that this plan of delivering a given amount of brine to the well in a stated time was practically automatic, the attendant having nothing to do except to keep the bottoms of the barrels supplied with salt.

DESCRIPTION OF STATIONS.

The stations from which water was collected were seven in number and are described below. Their locations are shown by the sketch map (fig. 16).

Station No. 1.—The station is the well at the public waterworks, 1,000 feet northeast of the Russell Pond well. The well is 321 feet deep and supplies the town with water. It is cased with 8-inch casing to 122 feet, only a short distance above the first water-bearing stratum. Within the 8-inch casing is inserted a 4½-inch casing which extends from the surface to a depth of 309 feet, at which point it was driven securely into a hard rock so as to form what was supposed to be a water-tight joint, cutting off all the water from the 123-foot water-bearing stratum above. The town water supply is pumped through this 4½-inch casing from the second water-bearing stratum, 311 feet below the surface. The second water-bearing stratum has a static head 2¾ feet greater than that of the first stratum. Nevertheless, it was thought that in case the 4½-inch casing was not absolutely water-tight at the point where it was driven into the rock, continuous pumping might lower the static head of the water from the second stratum sufficiently to set up a current from the stratum above, in which event sewage poured into the upper stratum would contaminate the lower.

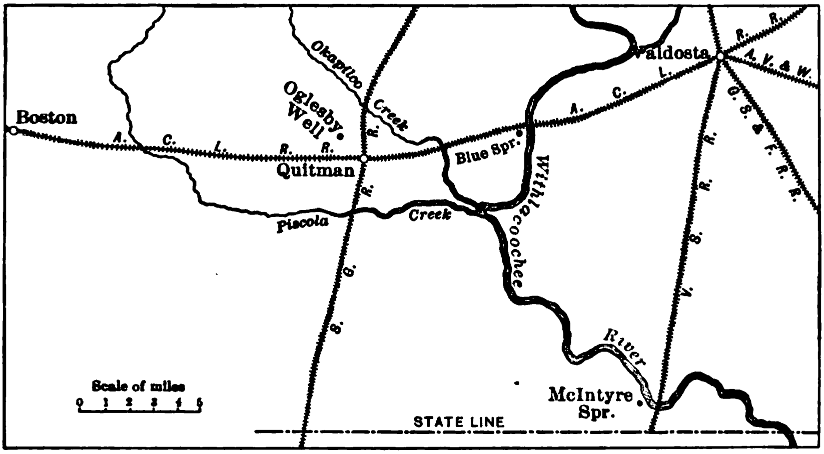


FIG. 16.—Sketch map showing location of Quitman experiment.

Station No. 2.—This is the "Old City well," 1,500 feet northeast of the Russell Pond well. The well used for this station is 500 feet deep, and was completed in 1884. It was originally cased to a point some distance below the first water-bearing stratum, but its lower part becoming obstructed by sand or some other material, the 6-inch casing was burst by an explosive at the first water-bearing stratum, in order to obtain water for public use. While the experiment here reported was being carried on, this well, which had not been in use for some months, was connected with the pumps at the waterworks station, so that the water might be procured at regular intervals.

Station No. 3.—This is the Oglesby well, located at the Oglesby Mills, three-fourths of a mile northwest of Quitman. This well was completed in May, 1903, and is only 92 feet deep. It is 6 inches in diameter and is cased to 78 feet. The water-bearing stratum was struck at 87 feet, at which point, it is said, the drill dropped into a cavity 4 feet in depth and immediately thereafter the water rose to within 48 feet of the surface. It will here be noted that the water-bearing stratum in the Oglesby well is much nearer the surface than the first water-bearing stratum encountered in the wells within the corporate limits of Quitman, and also that the static head of the water is nearer the surface. This difference, however, is due entirely to the fact that the ground at this point is lower than that at neighboring wells, and not, as might be supposed, to the occurrence of a different water-bearing stratum.

Station No. 4.—This station was established at Blue Spring, near the right bank of the Withlacoochee River, 6 miles east of Quitman. By aneroid measurement the spring was found to be about on a level with the static head of the water in the Russell Pond well, so that it seemed to be a possible outlet for the supposed underground stream into which the salt was introduced. At the time the samples were collected Blue Spring was flowing about 15,000,000 gallons in twenty-four hours. It was learned, however, that at one time during an extremely dry season, several years ago, the spring entirely ceased flowing.

Station No. 5.—This is McIntyre Spring, about 15 miles southeast of Quitman, only a short distance from the Georgia-Florida State line. The spring is located partially in the Withlacoochee River and appears to furnish a much greater volume of water than Blue Spring. Owing to the great distance of this spring from Quitman it was found impracticable to determine its elevation by aneroid barometer, but judging from the fall of the river it must be several feet below Blue Spring. A flood in the river during the time the samples were being collected submerged McIntyre Spring for some time, so that only a limited number of samples were procured from this station.

Station No. 6.—This is a deep well at Boston, Thomas County, 14 miles west of Quitman. The Boston well has a depth of 290 feet and was completed in June, 1900. It is reported that three water-bearing strata were penetrated in this well, at 120, 160, and 286 feet. The static head of the water in the third water-bearing stratum is said to be 69 feet above sea level, which is 70 feet below the static head of the water in the Russell Pond well.

Station No. 7.—This station is one of the deep wells at Valdosta, 17 miles east of Quitman. The well from which the samples were taken at Valdosta was the 8-inch well, now used to supply the city waterworks. This well is 500 feet deep, but its main water supply is said to come from a stratum at a depth of 260 feet, where the drill is reported to have entered a cavity 4 feet in depth. The static head of the water now in this well is 105 feet above sea level, which is 24 feet below the static head of the water in the Russell Pond well.

Additional station.—In addition to the stations here described there was also one kept up for a short time at the Quitman cotton factory; but, as the well was afterwards found not to be of sufficient depth to reach the water-bearing stratum into which the salt was introduced, it has been omitted in the tables and on the diagrams showing the variation of chlorine in the samples of water collected at the various stations.

SAMPLES OF WATER TAKEN.

The time at which the samples of water were taken at each station, the intervals between samples, and the number of samples themselves are shown in the following table:

Place, time, and number of samples of water taken.

Stations.	Date of first sample.	Interval between samples.	No.
		Hours.	
No. 1	Oct. 15, 12 noon	4	36
No. 2	do	4	31
No. 3	Oct. 15, 4 p. m.	8	30
No. 4	Oct. 16, 6 a. m.	12	40
No. 5	Oct. 19, 6 a. m.	24	[a] 11
No. 6	Oct. 19, 8 a. m.	24	[b] 16
No. 7	do	24	31

[a] Full number of samples not collected on account of high water.
[b] Fourteen samples lost by breakage in shipment.

CORRELATION OF WATER-BEARING STRATA.

In regard to the different water-bearing strata above noted in the Valdosta and Boston wells it might be stated that it was found impossible, with the meager data at hand, to correlate any of them with the water-bearing stratum in the Russell Pond well. In the absence of other data, an attempt was made to correlate the strata by means of chemical analyses of the water, but the results were unsatisfactory.

While it does not seem possible at present to correlate any of the strata with the Quitman stratum, into which the salt was introduced, there is but little doubt that they all occur in the Vicksburg limestone. Furthermore, as previously noted, the static head of the water in the Valdosta and Boston wells is greater than the static head of the water in the Quitman well by 24 and 69 feet, respectively. This would seem to indicate that the water-bearing strata are not continuous throughout the entire region, or that there is a flow converging toward Quitman, a condition not probable.

RESULTS.

Station No. 1.—The normal chlorine in the waterworks well was determined as 5.44 parts per 1,000,000. Four hours after the introduction of the salt in the Russell Pond well the amount of chlorine in the water, as shown by the samples, began to increase, reaching a maximum of 6.80 at 8 p. m. October 15, or twelve hours after the introduction of the salt. From this time on the water continued to show excess of chlorine in varying quantities for about five days, or as long as the salt water was poured in at the other well, finally subsiding to its normal amount on October 21.

Station No. 2.—The normal chlorine in the old Waterworks well appears to be 5.44, although a sample taken just before the experiment showed 6.12. The chlorine content of the water of this well began to rise within four hours after the insertion of the salt, reaching a maximum of 6.97 at 8 p. m. on October 15, from which time it gradually declined, with several fluctuations, until 8 p. m. October 19, after which it remained constant until October 21, at its normal amount.

Station No. 3.—The normal chlorine in the Oglesby well is 5.44. The water of this well was examined at intervals from October 15 to October 29. From October 15 to October 21 there were some fluctuations in the amount of chlorine, which, however, appear to have no relation to the introduction of the salt in the Russell Pond well. At 12 p. m. on October 21 a decided rise was noticed, which continued until 4 p. m. October 22, when it reached a maximum of 6.46. It remained at this point until 12 p. m. of the same day, after which it declined gradually, though with some fluctuations, until 12 p. m. October 26, when the normal was again reached.

Station No. 4.—The normal chlorine at Blue Spring appears to be 5.78 parts per 1,000,000. Tests were conducted from October 16 to November 4, but no variations in the amount of chlorine which could be attributed to the salt inserted at Quitman were observed.

Station No. 5.—The normal chlorine at McIntyre Spring is 5.78, the same as at Blue Spring. Samples were taken from October 19 to November 6, but no variations in the amount of chlorine referable to the introduction of salt at Quitman were noted.

Station No. 6.—The normal chlorine in the Boston well appears to be 6.80, and no persistent variations were observed during the interval from October 19 to November 24.

Station No. 7.—The normal chlorine in the Valdosta well is 5.44. No variations due to the insertion of salt at Quitman were noted.

From the preceding it will be noted that only three stations—namely, the Waterworks well, the Old City well, and the Oglesby well—show variations which can with any degree of certainty be attributed to the effect of salt introduced in the Russell Pond well. It will be observed that the maximum amount of chlorine in the two wells first named occurred at 8 p. m. October 15, just twelve hours after the first introduction of salt into the well. As both of these wells are within a short distance of the Russell Pond well, this result would naturally be expected; yet at the same time it is difficult to explain how the salt made its appearance in the Waterworks well, as it obtains its supply from a water-bearing stratum that lies 200 feet below the one into which the salt was introduced. It was surmised that the casing cutting off the upper water-bearing stratum from the one below did not form a water-tight joint at the point where it was driven into the rock, but allowed the water to flow downward when the pump was in action. In order to determine whether this supposition was true or not, the following test was made: The pump was started and run for a few minutes when a sample of the water was taken to determine the normal amount of chlorin present. There was then introduced through the 8-inch casing into the upper water-bearing stratum 15 pounds of salt in solution, and the pump was again started and run continuously for a half hour. During the time the pump was in operation samples were taken every five minutes. Analyses of these samples showed no increase of chlorine, demonstrating that the salt had not reached the second water-bearing stratum by the way of the suspected joint at the lower end of the 4½-inch casing elsewhere described. This test seemed to show that the chlorine in the original experiment did not reach the water in the second stratum by the way of any defect of the joint at the end of the 4½-inch casing. The test, however, can hardly be considered conclusive, owing to the small amount of salt used and the limited time the pump was operated after the salt was introduced. It is very probable that if the amount of salt had been larger and the samples had been taken at longer intervals, the presence of the salt would have been detected.

In regard to the Oglesby well it will be noticed that the salt was transmitted in a northwesterly direction, notwithstanding the fact that the general flow of underground waters of the region is supposed to be southward rather than northwestward.

In addition to the variation in the amount of chlorine here explained as probably due to the presence of the salt introduced into the Russell Pond well, there are also other variations which, with one exception, are unexplained. The exception referred to occurred at the old City Waterworks well. The diagram for this well shows that the amount of chlorine in the sample taken before the experiment was much higher than the normal. This was probably due to the presence of surface waters which had reached the water-bearing stratum below through the defective casing.

CONCLUSIONS.

From the notes above given on the Quitman experiment the following conclusions may be drawn:

1. The so-called underground stream, in the ordinary meaning of that term, does not exist in the wells investigated.

2. The water, which has a motion of probably not over 200 feet per hour, occurs in a porous, cavernous limestone, several feet in thickness.

3. Sewage introduced into the first water-bearing stratum will contaminate all of the wells in the vicinity that attain a depth of 120 feet or more.

4. The upper water-bearing stratum in the Waterworks well is not completely cut off from the water-bearing stratum below, so that the water from the lower stratum is likely to be contaminated from the stratum above.

THE NEW ARTESIAN WATER SUPPLY AT ITHACA, N. Y.

By FRANCIS L. WHITNEY.

The object of this paper is to call attention to steps taken at Ithaca to obtain a pure water supply from underground sources after the pollution of the surface sources had given rise to a severe typhoid epidemic. The conditions existing at Ithaca, as regards underground waters, are probably duplicated at many points in New York, New England, and elsewhere, and attention is called to the possibility, under favorable conditions, of procuring adequate supplies, even for towns or cities of some size, from the glacial gravels of the deeply filled valleys of these regions. Such supplies may not always be available, but the possibility that they may be procured can usually be determined by a few inexpensive test wells.

FACTORS LEADING TO CHANGE OF SUPPLY.

Old water supply.—Up to the early part of 1903 the city of Ithaca obtained the larger part of its water supply from Sixmile Creek, a stream entering Cayuga Lake from the southeast at Ithaca. The pumping station was located in the outskirts of the city, on the southeast side. The creek is between 15 and 20 miles long. In general its drainage area is thinly populated, but two towns having an aggregate population of several hundred inhabitants, are located directly on the stream, which, in fact, receives all the drainage from them.

An additional water supply was obtained at Buttermilk Falls, on a small creek about 1½ miles south of Ithaca. There are very few houses in its drainage area.

Cornell University derives its supply from Fall Creek, a stream that empties into Cayuga Lake at its south end.

Typhoid epidemic.— It had long been recognized that these waters, especially that of Sixmile Creek, were liable to pollution, and precautionary systematic examinations of the water were made from time to time. These analyses were made by Prof. E. M. Chamot, of Cornell University. Some difficulty existed in the interpretation of the analyses, because of the fact that a number of flowing salt wells were tributary to the stream, so that it was not possible to determine what part, if any, of the chlorine that the water contained was due to sewage or similar pollution.

The water gave general satisfaction until about the beginning of 1903, when an exceptionally severe epidemic of typhoid fever broke out in the city. Hundreds of residents, including many students of Cornell University, were stricken, and the percentage of deaths was very high. The public was thoroughly aroused to the necessity of taking immediate and radical steps for determining the cause of the epidemic and for furnishing a new water supply, provided the source of danger was found to lie in the old supply.

It was found that the city supply from Buttermilk Falls and the college supply from Fall Creek were unpolluted. Sixmile Creek, on the contrary, was proved to be highly polluted, and it was seen that this was the probable cause of the epidemic.

Proposed dam on Sixmile Creek.—During 1902 the Waterworks Company began the erection of a high dam on Sixmile Creek, in order to provide a supplementary source of supply. The dam was designed to be 90 feet high and 100 feet wide. Many of the citizens of the town and some experts considered the dam unsafe and vigorous protests were made. The protests were, however, without result, and the company continued the work of construction. The feeling against the company became very strong and was doubtless a factor in the controversy which arose over the question of securing artesian water.

Action of water commissioners.—On February 16, 1903, the water commissioners met and discussed the feasibility of installing a filtration plant. The plan was proposed by President Schurman, of the university. Prof. E. M. Chamot testified that such a plant would not act as a perfect sterilizer, although if properly constructed and controlled it would remove 98 to 99 per cent of the bacteria. The plan received little support.

Commissioner Horton called attention to the expense of filtering and the ease with which a company can furnish, without detection, unfiltered water, and advocated artesian wells as a source of supply. It was thought that such wells could be obtained within a radius of 10 miles of the city.

It was urged by Professor Chamot that most of the artesian-well water of the locality was too hard for household purposes, but that it could be used in boilers, as attested by the fact that it had for eight years been used in those at the salt plant without bad effects. A further objection to the use of artesian wells lay in the fact that the city might be liable for damages resulting from the loss of water in adjacent wells. The drilling of test wells, the effect of which it was proposed to observe carefully, was advised as a precautionary measure.

Action of common council.—At a meeting of the common council early in the year President Schurman urged immediate efforts to obtain uncontaminated supplies, stating that it would become necessary to close the university unless a satisfactory supply was obtained by September 1, 1903. He reported that the executive committee and a number of trustees of the university had considered the advisability of sinking artesian wells, and had reported that it would probably not be possible to obtain from such wells the 2,000,000 gallons of water consumed daily by the city. In consideration of the necessity of obtaining pure supplies by September 1, it was recommended that the filtration plant be installed. This proposition was adopted by the council, but it was decided, before proceeding further, to submit the subject to the referendum of the people. A special election was ordered, to take place on March 2, to determine whether the city should undertake the ownership of its water supply. This election resulted in favor of municipal ownership.

Action of committee of one hundred.—Following the election a committee of one hundred was appointed from among the representative men of the city which agreed to subscribe to the amount of $10,000 or more toward procuring an immediate pure supply and for conducting experiments to determine the probability of a permanent supply of artesian water from the Freeville basin. The Fourth street test well, described on a subsequent page, was sunk by this committee.

FREEVILLE ARTESIAN BASIN.

The Freeville basin is a portion of the deep, gravel-filled valley of Fall Creek lying in the vicinity of Freeville, about 10 miles northeast of Ithaca. The watershed contributing to the basin covers 75 square miles, while the basin proper has an area of from 15 to 25 square miles. It was estimated that 10,000,000 gallons of water daily could be obtained from this basin, although the nature of the material and the slope of the hydraulic grade, or underground water surface, was practically unknown. Because of the lack of definite information in regard to the basin and its distance from the city the project of obtaining water supply from it was finally abandoned.

ITHACA ARTESIAN BASIN.

Attention was then directed to the valley in which the city of Ithaca lies. An examination of the geology of the region showed that because of the slope of the rocks to the south, while their outcrop was at a lower level to the north, they could not be expected to yield flowing water. The fineness of the texture of the rocks is also such that their water-holding capacity is small.

The conditions for a supply from the gravels filling the valley, however, are much more favorable. Such wells as had been drilled obtained considerable supplies, and it appeared probable that with additional wells a supply sufficient to meet the needs of the city could be obtained.

The underground water of the region is probably derived by absorption from the waters brought in from the south by Coy Glen, Buttermilk Creek, Enfield Creek, and other streams tributary to the main valley occupied by Cayuga inlet. Cayuga Lake will apparently have little bearing on the water supplies of the gravels, its surface being considerably lower than the mouth of the wells. Prof. G. D. Harris suggested the use of screens adjusted in the casing of the wells at each water bed in order that all producing horizons might be drawn upon.

It was not regarded as essential to the success of the artesian supply that the wells should actually flow, it making very little difference in the cost of distribution whether the water stood a few feet above or a few feet below the surface. Jamestown, in western New York, is supplied with water from a deeply gravel-filled channel. At the start the wells rose perhaps 25 feet above the surface, but as more wells have been sunk into the water-bearing gravels and a considerable supply drawn from them the old wells have ceased to flow, all the larger wells being connected with powerful steam pumps.

It was conceded that the water supply of Cayuga inlet valley would easily supply Ithaca proper, while if necessary the university and portions of the city in its vicinity could be supplied by Fall Creek.

WELLS IN THE ITHACA BASIN.

The Illston well.—The Illston well, which is about 287 feet deep, was sunk by Mr. Illston for the purpose of obtaining pure water for the manufacture of ice. After much labor and expense he succeeded in obtaining a well which gave a pressure of about 13 pounds per square inch and a temperature of 54° F. Tests made by Mr. E. B. Kay on March 6, 1903, showed that, with the pipe 8 feet above ground, 403,142 gallons of water ran from the well daily, the test being made with a weir after the well had run freely for one hour. Mr. Kay estimated that had the test been made at the surface of the ground the result would have been more than 425,000 gallons. By the use of an air lift or other pump the capacity would probably be increased at least 50 per cent, and it is not impossible that 1,000,000 gallons daily might be procured from this well alone. A second test, made March 8, after the well had flowed twenty-four hours, showed an output of 405,000 gallons a day. The flow was even stronger than in the former test. Records at the Cornell chemical laboratories show that the analysis of water from this well is as follows:

Analysis of water from Illston well.

	Parts per million.
Free ammonia	0.480
Albuminoid ammonia	0.005
Nitrogen as nitrites	None.
Nitrogen as nitrates	Trace.
Oxygen consumed	0.644
Chlorine as chlorides	61.640
Total solid residue	304.000
Loss of solids on ignition	78.000

Comparative analyses made by Professor Chamot on the Illston and other waters of this vicinity showed that in 1,000,000 parts the Illston water contained 309 parts solid matter; Fall Creek water, 309 parts; Buttermilk Creek water, 200 parts; springs in vicinity of the city, 165 to 200 parts; city well water, 500 parts, and Forest Home well water, 670 parts per million.

From the analysis it appears that the Illston well water is softer than that of most of the wells and springs in the city or at Forest Home, as soft as the Fall Creek water, and almost as soft as Buttermilk Creek water.

Salt well.—About eight years ago the National Salt Company began to sink its first well to the salt bed. A 14-inch hole was drilled. For the first hundred feet the drill went through a stratum of clay, in which no water was found. At the depth of 100 feet the drill broke through the clay into a gravel bed, upon which the hole was instantly filled with pure, clear water.

After going through the gravel, 100 feet beyond the water vein, the drill was brought to the surface, and in the corner of the derrick house another well, this one 6¼ inches in diameter, was sunk to a depth of about 120 feet, the lower 20 feet being in the gravel. The water from this well was clear, despite the fact that the drill had ground up the gravel and had created a condition which, naturally, would have caused the water to be turbid. A third well, of the same size as the last, was sunk, and then the drilling of the first and deeper well was resumed. After the completion of the plant a pump was attached to one of the wells. The flow was so copious that the engine was shut off to half its power, and for eight years only a small part of the water which might be drawn from the well has been used, although thousands of gallons are consumed daily at the plant.

Fourth street test well.—With the belief that other wells sunk in this vicinity would prove successful a test well was bored near Fourth street. This well was readily drilled to the water-bearing stratum, which was struck at the depth of 91 feet. When the gravel was reached the 6-inch pipe was quickly filled with water. Another length of pipe was then added, and the well was completed at a depth of 123 feet, with 32 feet of pipe in the gravel.

This well was then tested by pumping for several hours with a steam fire engine. Although the engine was worked to its full capacity there was no diminution of the water supply. The well, however, has since become choked with fine sand, which has gradually filled the screen. It is believed, however, that if properly developed it may again be made to yield abundantly.

Wells drilled for temporary supply.—Meanwhile workmen, under the direction of the water board, were drilling several wells for a temporary supply. These wells are located on the lowlands in the valley of Cayuga Lake, along the lines of the Delaware, Lackawanna, and Western Railroad Company and the Lehigh Valley Railroad Company, near the intersection of Clinton street with the railroads. The lowlands are level and swampy, being only about 3 feet above Cayuga Lake. As shown by the accompanying map (fig. 17) they are within a few feet of the Illston well, south of the city.

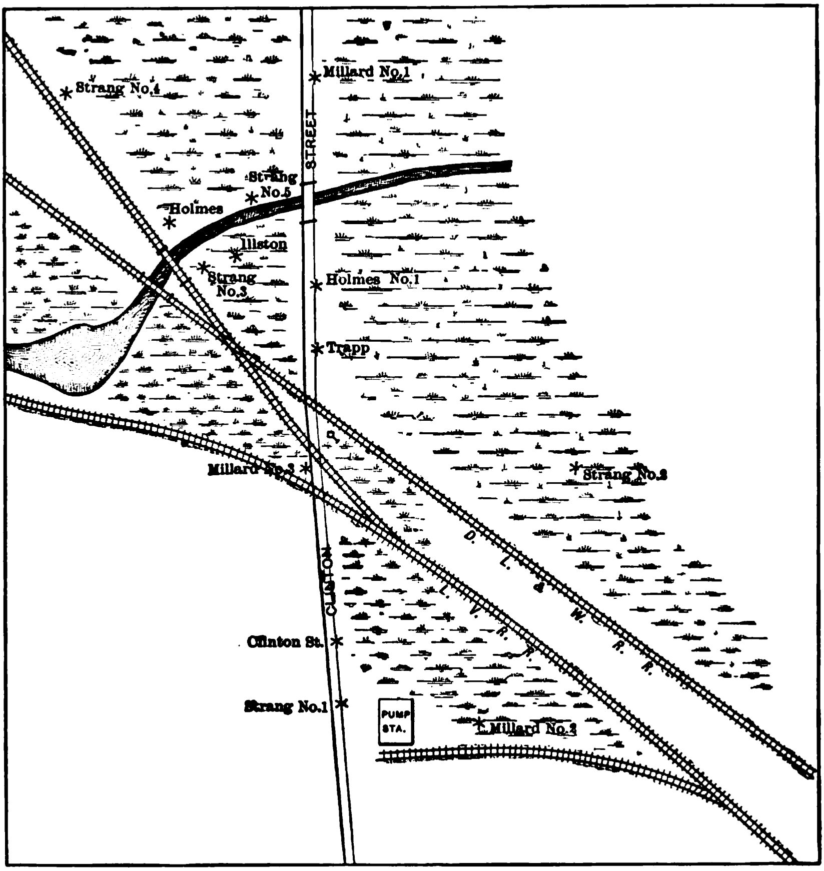


Fig. 17.—Sketch map showing location of temporary supply wells near Ithaca.

The wells were all sunk by a walking-beam drill, assisted by hydraulic jet to remove the fine sand when the water-bearing strata was reached.

Of the 13 wells put down by the board only 3 are dry, 2 ending in black shale, the others in fine sand and gravel. Many have an excellent head, those nearest the Illston well, already described, having the greatest. One, known as Strang No. 3, had, at the time of boring, a static head of 17½ pounds. Some of the wells nevertheless required developing, and were opened by exploding dynamite at their bottoms, the loosened material being then removed by washing. In the Trapp well over 30 pounds of dynamite were used for this purpose.

As already stated, the Illston well yields with an air lift 425,000 gallons daily. The wells sunk for the temporary supply draw their water from the same source. What the wells will yield, however, is not yet known, although it had been found that the water in the various wells is affected by the pumping of others in the series. The water board estimates that the wells when pumped will have a capacity of 3,000,000 gallons daily.

GEOLOGY OF THE SUPPLY.

The diagrammatic sections in Pl. V, together with the written records on pages 64 to 66 indicate the manner in which the materials are distributed in the different wells. It will be seen that there is considerable variation in the upper and lower portions of the wells, although a certain system in the character of the deposits prevails. At the top there is a bed of mucky clay about 6 feet thick. Below this is a pure clay, or a clay containing in some instances considerable amounts of sand or gravel, which extends to a depth from about 50 or more feet, beneath which is from 20 to 50 feet or more of prevailingly sandy or gravelly material, in which some clay may also occur. These strata carry water, which will rise to within about 10 feet of the surface. None of this water is admitted to the wells, but is cased off so as to avoid any possibility of contamination from surface water. The stratum of sand and gravel last mentioned is frequently overlain by logs in a good state of preservation, which the drills penetrate with difficulty. Underlying the gravel and sand is a stratum of clay that extends to depths ranging from 210 to 250 feet, where a mixture of gravel and clay is encountered that extends downward to depths varying from 280 to 290 feet below the surface. The lower part of this stratum was in many cases a very hard and compact hardpan, directly below which is the stratum of gravel and sand from which the supply of water is drawn. As the water is taken only from this stratum, which lies 285 feet below the surface and is protected by a great thickness of clay, surface pollution becomes practically impossible.

The abundant supply can be attributed to the general conditions of the valley. On either side are hills attaining a height of about

1,000 feet and forming an immense catchment area. Underneath the drift are the Portage, Genesee, and Hamilton shales, and other rocks, dipping southward. The slope of the hills being nearly at right angles to the dip of the beds, the water flows downward into the valley instead of percolating through the underlying rocks. At a distance of 8 miles south of the city the floor of the valley is about 472 feet higher than at the wells. The water from the hills of this region finds its way into the gravel and sand deposits of the valley, and by these is conveyed toward the lake.

Wells drilled outside a rather definitely limited area either fail to obtain water or procure only small supplies with little head. Wells drilled along a certain line, however, procure water under considerable pressure. The facts indicate the probable presence of a rather definite and limited water course through sand and gravel overlain by impervious clays.

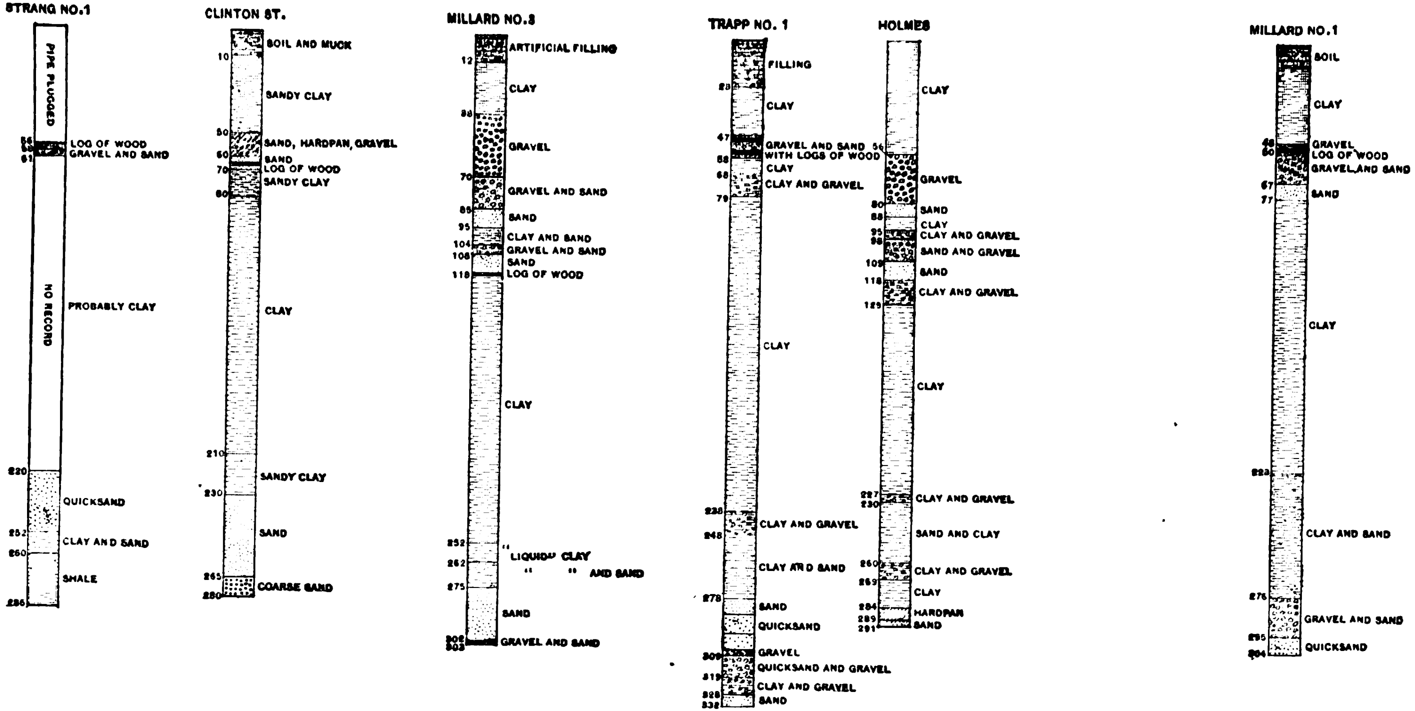
WELL RECORDS.

The sections of six of the artesian wells in the vicinity of Ithaca have been given in Pl. V. Below are given records of a number of additional wells.

SOUTH WELL.

Material.	Thickness.	Depth to base.
	Feet.	*Feet.*
Soil	5	5
Blue clay	7	12
Clay	8	20
Sandy clay and wood	10	30
Sandy clay	10	40
Gravel and clay	10	50
Clay	10	60
Clay and gravel	10	70
Clay	65	135
Sandy clay	65	200
Sand	10	210
Coarse sand	10	220
Coarse to fine sand	10	230
Coarse sand; struck water	2	232

Located 1,500 feet up the valley from Clinton street, Ithaca, and about 70 feet east from the Delaware, Lackawanna and Western Railroad. Authority, Mr. Partridge.



SECTIONS OF TEMPORARY SUPPLY WELLS.

MILLARD WELL NO. 2.

Material.	Thickness.	Depth to base.
	Feet.	*Feet.*
Clay	44	44
Sand and gravel	31	75
Quicksand	3	78
Clay	123	201
Clay and gravel	21	222
Quicksand	18	240
Cemented gravel	4	244
Fine sand and clay mixed	7	251
Hardpan	6	257
1 bucket coarse gravel; black sand	1	258
Hardpan	1	259
Struck flowing water	....	259

STRANG WELL NO. 2.

Driven with plugged pipe	87	87
Fine sand	10	97
Clay	116	213
Clay with large stones	22	235
Thin clay	33	268
Thin clay and fine sand	11	279
Fine sand	8	287
3 or 4 buckets of sand and coarse gravel.		
Fine sand	13	300
Clay and gravel, hardpan	7	307
Clay and gravel with large stone	6	313
Clay and gravel with streaks of fine sand	3	316
Clay and sharp black sand	11	327
Clay, fine sand, and gravel	1	328
Clay and black sand	2	330
Soft black shale rock and sand	12	342
Black shale	10	352
Dry hole.		

STRANG WELL NO. 3.

Pipe driven with end plugged	110	110
Log	2	112
Clay and sand	11	123
Clay	47	170
Clay and sand	70	240
Quicksand	19	259
Black sand and some clay and fine sand mixed	16	275
Do	5	280
Struck water	....	280

STRANG WELL NO. 4.

Material.	Thickness.	Depth to base.
	Feet.	*Feet.*
Driven with plugged pipe	110	110
Clay and large gravel	10	120
Fine sand	10	130
Clay	112	242
Hard clay and stone	6	248
Fine sand	32	280
Struck water	....	280

STRANG WELL NO. 5.

Driven with plugged pipe	108	108
Clay and stone	7	115
Fine sand	8	123
Clay	121	244
Clay and stone	12	256
Clay	14	270
Gravel; struck water	6	276

PRESENT CONDITIONS.

The total number of wells sunk is 14, of which two, put down in the first prospecting, are at such a distance from the station and collecting well as to make it impracticable to connect with them on account of cost, and three are dry or nearly dry. The remaining nine productive wells vary in flow from 50,000 gallons to 430,000 gallons each per day of twenty-four hours, and the static heads vary from 16 to 18 pounds.

The flow is collected by a system of pipes and laterals and delivered to a circular brick cistern or well, 16 feet in diameter and 18 feet deep, where any gravel or sand is deposited, so that it may not reach the pumps. The walls of the collecting well are 17 inches thick, and are made water-tight by a thick wall of puddled blue clay that entirely surrounds the well and extends from the surface downward to a depth of 6 feet, reaching the stratum of clay underlying the soil.

In the meantime the waterworks company has constructed a filtration plant of the mechanical type, from which those who are willing to take real or fancied filtered water obtain their supplies.

For a permanent supply deep wells in the valley of Sixmile Creek are contemplated, although not yet decided upon. These can be so located that the water may be distributed by a gravity system.

DRILLED WELLS OF THE TRIASSIC AREA OF THE CONNECTICUT VALLEY.

By W. H. C. Pynchon.

INTRODUCTION.

Location and area.—The Triassic area, so called from the fact that it is underlain by rocks of Triassic age, is the lowland belt extending from New Haven in a direction slightly east of north to Northfield, Mass., not far from the New Hampshire line—a distance of about 110 miles (fig. 18). Its width at New Haven is about 3 miles. To the north it expands until at the Massachusetts line it has a width of 20 miles, from which it gradually declines to a width of about a mile at its northern end.

It is an area of soft sandstones and shales, with occasional trap ridges, lying in a broad depression between harder, more or less crystalline rocks. It is traversed from its northern end southward to beyond Middletown by the Connecticut River and is frequently spoken of as the Connecticut Valley lowland.

General conditions.—The sedimentary rocks of the Triassic area vary from coarse conglomerates through sandstone to fine clay shales, interbedded with which are thick sheets of trap. The dip is a little south of east and averages about 14 degrees. The rocks, except the traps, are porous, holding up to 30 per cent of their own volume of water, and the dips are such that artesian flows would ordinarily be expected in the lower valleys. Such flows are sometimes obtained, though, because of disturbance by faulting and the presence of numerous joints, the waters of the area are uncertain as to quantity and as to the height to which they will rise. The Triassic rocks are, nevertheless, a very important source of water, and it is with a view of describing the conditions to drillers and well owners that the following account has been prepared. The region involved in the problem is not limited by geographical but by geological boundaries, being confined to the area of outcrop of the Triassic rocks.

Nature of investigation.—In the Triassic area the occurrence of water is dependent directly upon the texture and structure of the rocks, and is therefore strictly geological. To fully understand its occurrence a knowledge of the geological conditions is necessary. This knowledge may be obtained in part by an examination of the rocks where they are exposed at the surface, but a full insight into the question requires an intimate understanding of the conditions as they are disclosed by borings made for wells. No one is in a better position to know the underground conditions in his own wells than the driller, but his detailed knowledge rarely extends to the wells of other drillers and almost never covers the whole field. It is by combining information obtained from local authorities throughout the entire field and from his own personal observation that the geologist is able to present a comprehensive view of the entire region.

The present paper is a result of the method of investigation outlined above. Published descriptions of the region were consulted, additional field work was done in places concerning which further information was desired, and well records and other information furnished by drillers was collected from all parts of the area.

Collection of well data.—At the beginning of the investigation much information concerning well records was obtained by correspondence. Printed or typewritten blanks, containing a number of questions relating to the owner, location, diameter, and depth of well; quantity, quality, and height of water; materials encountered, additional well owners, drillers, etc., were sent out. The typewritten blanks were returned in almost every case, and a large number of the printed forms were also received. These furnished a good basis for planning field work, which was then undertaken. In the field, personal interviews were had with drillers and well owners and facts relating to the wells were obtained at first hand. These facts were afterwards studied and compared with one another and the resulting information was compiled for publication in the present report.

Special thanks are due to Mr. C. L. Grant and Mr. H. B. King, well drillers, of Hartford, Conn., for records and valuable information relating to wells of the area.

TOPOGRAPHY.

The topography[a] of the region is in general such as might be expected from the general geological structure. The hard crystalline rocks of the eastern and western uplands stand well above the region of soft Triassic sediments, surrounding them like a barrier. At its northern limit the lowland has an elevation of from 400 to 500 feet above sea level, but the land slopes steadily downward toward the south until, in the region of New Haven, there are portions which are only slightly above sea level. As would be expected, the harder sedimentary beds find topographic expression in low ridges following the strike of the rocks in a generally north-to-south direction, their steeper faces being toward the west, as the beds dip eastward. But it is to the highly resistant trap sheets that the valley owes its most striking topographic features. Throughout the whole Triassic area the trap ranges dominate the lowlands in strong ridges that run from north to south and present bold cliffs on the west and gentle slopes on the east. The western cliffs of these ridges are buried in some cases almost to their summits by a heavy talus of fragments which the frost has split from their faces. These slopes of talus, topped by perpendicular cliffs, have a marked individuality, and though of no great elevation have long been spoken of as "mountains" throughout the region. The highest of these ridges in Massachusetts is Mount Tom, about 10 miles northwest of Springfield, which has an elevation of 1,200 feet above sea level, while the most conspicuous in Connecticut is West Peak, in the Hanging Hills of Meriden, with an elevation of 1,007 feet.

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[a] The entire areas of the States of Connecticut and Massachusetts have been mapped by the United States Geological Survey. The complete series of maps includes about 70 sheets, of which about 15 lie within the area under discussion. The separate sheets are sold by the Survey for 5 cents each—the approximate cost of printing. Lists can be had on application to the Survey.

GEOLOGY.

PREVIOUS INVESTIGATIONS.

Soon after the beginning of the nineteenth century the geology and the mineralogy of the Triassic area of Connecticut and Massachusetts began to attract attention, papers on the subject having been published by the elder Professor Silliman, of Yale, as early as 1814. The first geologist to make a thorough study of the Connecticut section was Dr. James Gates Percival, who published in 1842, under State auspices, a "Report of the Geology of Connecticut." Dr. Charles Upham Shepard had published in 1837 his "Report on the Geological Survey of Connecticut," but this work was confined almost wholly to the mineral resources of the State. At about the same time the portion lying in Massachusetts received attention from Prof. Edward Hitchcock, of Amherst College. Among the geologists who have since devoted special attention to the region are Prof. J. D. Dana, of Yale, Prof. B. K. Emerson, of Amherst, and Prof. W. M. Davis, of Harvard. The latest and most exhaustive treatise on the Triassic of Massachusetts is Prof. B. K. Emerson's "Geology of Old Hampshire County, Massachusetts."[a] The latest and fullest treatise on the Connecticut section is Prof. W. M. Davis's "Triassic Formation of Connecticut."[b]

The geology of the Connecticut Valley lowland is interesting from many standpoints. The manner in which quiet processes of deposition have alternated with volcanic or other igneous action presents in itself a broad field of study, but the elaborate manifestations of faulting and displacement and the complicated structures and topographic forms which have been developed in the region are the chief sources of interest to the geologist. It is not within the province of this paper, however, to take up the geological history of the area, attention being necessarily confined to the existing structure without regard to the processes by which this structure has been produced, except in so far as they influence the underground water supply. It is from this standpoint alone that the following description of the geology and topography of the region is given, the reader being referred for further information to the publications mentioned above.

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[a] Mon. U. S. Geol. Survey, vol. 29, 1898.

[b] Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, pp. 1-192.

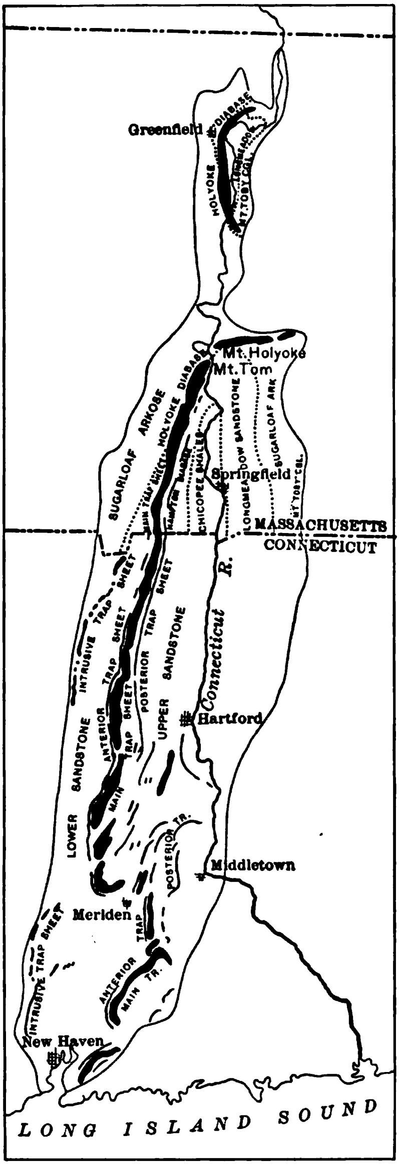

FIG. 18.—Geologic sketch map of the Triassic area of the Connecticut Valley.

GENERAL RELATIONS.

Both the eastern and the western portions of Connecticut are occupied by extensive highlands. These consist of ancient metamorphic rocks, deeply eroded by streams and overlain by glacial drift. The western upland is the more elevated, attaining at one point, Bear Mountain, a height of 2,355 feet above the sea. In Massachusetts this western upland is even more rugged than in Connecticut, and contains within its borders the famous Berkshire Hills. The eastern upland of Massachusetts is, like that of Connecticut, much less rugged than the western. The rocks are highly metamorphosed and deeply dissected by the streams which traverse them. Professor Emerson assigns the chief part of the metamorphosed rocks in Franklin, Hampshire, and Hampden counties, Mass., to the Silurian, a considerable portion to the Cambrian, two much smaller portions to the Upper Devonian and the Carboniferous, and a very small portion to the pre-Cambrian. It is probable that a detailed study of the uplands of Connecticut would show that the rocks comprising them would fall under a similar classification.

CHARACTER OF DEPOSITS.

Nature of the rocks.—Between the eastern and the western uplands, occupying a depression in the older rocks, lies the Connecticut Valley lowland, the limits of which have already been stated (p. 67). Its rocks all belong to the Triassic system. The greater portion of these rocks consists of comparatively soft sedimentary beds which are now so tilted that they have a rather uniform dip eastward of about 15 degrees. Interspersed with these rocks are to be found, however, certain sheets of volcanic lava (trap), generally interbedded between the strata of the sedimentary rocks, in nearly all cases in perfect conformity with the beds they overlie.

General structure.—A section across the Triassic area, as constructed by Professor Davis, is shown in fig. 19. The succession of the sandstones and traps, the uniform eastward dip of the beds of about 15 degrees and their displacement by faulting are strikingly brought out.

Succession and distribution of beds.—The portion of the Triassic area in Massachusetts and that in Connecticut were studied, as stated, by two geologists working independently, and in general the same conclusions were reached by both. The uniformly eastward dip, the succession from lower and older rocks on the west to higher and younger at the center of the area, the presence of conglomerates along the border, the succession of trap sheets, and the presence of great numbers of faults are recognized by both. In the details of mapping, however, different subdivisions of the rocks were made in the two States, and there is some difference of opinion as to the succession of beds in the eastern portion of the valley and the character of the contact along that margin. Fig. 18 shows the distribution of the rocks in both the Massachusetts and Connecticut areas as mapped by Professor Emerson[a] and Professor Davis[b] respectively. In the following table are shown the equivalency of the divisions recognized in the two States. In addition to the formations given for the Massachusetts area there are the minor Black Rock diabase and the Granby tuff or ash beds. In Connecticut there is in addition what has been known as the intrusive trap sheet. These minor beds will be considered on a subsequent page.

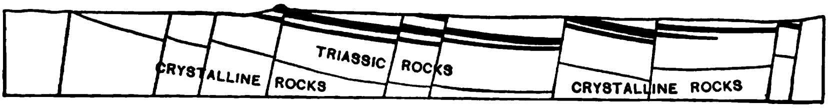

FIG. 19.—Generalized section across the Triassic area of the Connecticut Valley.

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[a] Emerson, B. K., Geology of old Hampshire County, Massachusetts: Mon. U. S. Geol. Survey, vol. 29, 1898.

[b] Davis, W. M., The Triassic formation in Connecticut: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898.

Table showing correlation of Triassic rocks in Massachusetts and Connecticut.

Subdivisions of B. K. Emerson in Massachusetts.		Subdivisions of J. G. Percival and W. M. Davis in Connecticut.
Chicopee shales		Upper sandstones, including also Mount Toby conglomerate and part of Sugarloaf arkose.
Longmeadow sandstone and included traps.	Sandstone, shale, etc	
	Hampton diabase (trap)	Posterior trap sheet.
	Sandstone, shale, etc	Posterior shale.
	Holyoke diabase (trap)	Main trap sheet.
	Sandstone, shale, etc	Anterior shales.
	Talcott diabase (trap)	Anterior trap sheet.
	Sandstone, shale, etc	Lower sandstone.
Sugarloaf arkose		
Mount Toby conglomerate		Not differentiated.

DESCRIPTION OF ROCKS.

Mount Toby conglomerate.—This is a coarse conglomerate, composed of fragments of slaty rocks, schist, and quartz, ranging from 2 inches to 4 feet in diameter, which forms a narrow band along the eastern border of the Triassic area in Massachusetts, extending from the Boston and Albany Railroad, near Ellis, southward to the State line, and on the same side from a point just north of Amherst to the extreme northern end of the area. It has not been differentiated in Connecticut, but undoubtedly extends along the eastern border in at least the northern portion of the State.

Sugarloaf arkose ("Lower sandstone" of Davis in part).—This is a coarse buff to pale red sandstone or conglomerate, made up largely of granite fragments that were derived from rocks lying farther west. It forms the western border of the Triassic area in Massachusetts, and bends around and forms the eastern border, except where it is separated from the crystalline rocks by the Mount Toby conglomerate. It is the equivalent of the conglomeratic portions of the "Lower sandstone" of Connecticut, where the latter rests in contact with the western border of the area.

Longmeadow sandstone and its Connecticut equivalents.—The sandstone occurs as a broad band inside of the Sugarloaf arkose belt. It is largely of the red or brown variety of sandstone, known as brownstone, which is so largely quarried, but includes many thin beds of shale. Interbedded with the sandstone are also thick beds of traps, which were laid down as lava sheets at various times during the period when the sandstones were deposited. The Longmeadow sandstone includes the nonconglomeratic portion of the lower sandstones of Connecticut, and the Anterior, Posterior, and a portion of the Upper shales or sandstones of Connecticut.

Talcott diabase (*Anterior trap sheet*).—This is a massive dark-colored trap that forms an important feature in the Connecticut area, where it is known as the Western trap range, but does not enter Massachusetts. It is a bedded sheet, originally formed as a volcanic flow on an old surface during the period of deposition of the sandstone.

Holyoke diabase (*Main trap sheet*).—This is a dark, dense trap bed, several hundred feet thick, that extends with a few breaks from the northern to the southern portion of the area. Because of its resistance to erosion it forms a conspicuous ridge, frequently called a mountain, as at Mount Tom and Mount Holyoke. It is sometimes known as the Eastern trap range. Like the Talcott diabase it was laid down as a surface lava flow.

Hampton diabase (*Posterior trap sheet*).—This is a relatively thin but at the same time persistent sheet that extends with some interruptions from near Mount Tom on the north to Long Island Sound on the south. It does not commonly give rise to a conspicuous ridge. Like the preceding sheets it was a surface flow.

Black rock diabase.—This is a diabase which, instead of flowing out over the old sandstone surfaces, was forced or intruded through the sandstones and the older Holyoke and Hampton traps as dikes or other igneous masses. It is found only in the region southeast of the Mount Tom and Mount Holyoke ridges in Massachusetts.

Granby tuff.—This is a sandstone or conglomerate, made up of volcanic débris, possibly derived from the volcanic eruptions accompanying the intrusion of the Black Rock diabase. Its distribution is much the same as the latter.

Intrusive traps in Connecticut.—The intrusive traps are of two types—intrusive sheets and dikes. The former is represented by the important trap sheet that was injected between certain of the lower sandstone beds near the western border of the Triassic area, and that extends from the Massachusetts line southward for nearly 20 miles, and again from near Southington to New Haven. The dikes are represented by smaller and more isolated masses, having approximately vertical attitudes cutting across the bedding of the sandstones.

Chicopee shale.—This is a band of dark-gray shaly sandstone, with some shales, that extends along the Connecticut River from Holyoke southward into Connecticut. In that State it has not been differentiated.

FAULTING.

When first formed both the sedimentary beds and the trap sheets were continuous and unbroken. If simply tilted and subjected to erosion such beds would give rise to continuous ridges, but in reality the latter are broken and their component parts shifted in relation to one another. This shifting is due to movements which have taken place along certain lines of fracture, and which in some regions have broken the rocks into a series of blocks bounded by faults and known as fault blocks. The faults are abundant in the Triassic area, both in Connecticut and in Massachusetts, reaching a high development in the region of the Hanging Hills of Meriden. In direction they commonly run from northeast to southwest, transversely to the strike of the beds, but some northwest-southeast faults occur. In a given district they are usually parallel to one another. In many places they are separated by intervals of only a fraction of a mile, the result being the subdivision of the rocks into long narrow blocks slightly offset as regards one another. In most cases there has also been much movement in a vertical direction.

In these dislocations there is to be found the greatest variation in length of fault line and amount of displacement. At one end of the series stand the small local faults, which can be traced for only a few feet and which show only a few inches of slipping; at the other end may be placed the great fault which separates the Hanging Hills from Lamentation Mountain. This fault crosses the whole lowland from northeast to southwest, penetrating both the eastern and the western uplands and having a total length of about 40 miles.[a] The upthrow is on the east of the fault line and is so great that the lower sandstones under Lamentation Mountain abut against the Posterior shales of Cathole Peaks, the most eastern member of the Hanging Hills. The fault gap between these two portions of the main trap sheet is a mile across. Faults of considerable movement everywhere leave distinct notches in the crests of the various trap ridges. At these points erosion, acting along the fault line, has cut deep gorges, some of which reach the dignity of passes, flanked by long slopes of rocky talus topped by perpendicular cliffs. Excellent examples of these fault gaps are Cathole Pass, between Cathole Peaks and Notch Mountain, and Reservoir Notch, between Notch Mountain and West Peak, both in the Hanging Hills.

Throughout the southern half of the Connecticut area, from about the latitude of Hartford to Long Island Sound, the faults are closely parallel, and run from northeast to southwest, the upthrow always being on the eastern side. As a combined result of this displacement and subsequent erosion there is, as we proceed southward, a constantly recurring recession of the outcrop of the various members of the series, this overlapping arrangement being specially well developed in the vicinity of Meriden. From about the latitude of Hartford northward to the Massachusetts State line the faults, though still oblique in character, run from northwest to southeast. The upthrow is still on the eastern side of the fault lines, so that there is still a tendency to an eastward recession of the outcrops, but in a manner the reverse of that which is seen in the southern portion of the valley.

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[a] Davis, W. M., The Triassic formation of Connecticut: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2 1898, p. 100.

In the Massachusetts area the faults in the Triassic are fewer and of less importance. Faults of both the varieties mentioned occur, as will be seen from Professor Emerson's map,[a] but they produce a less striking effect on the arrangement of the chief ridges of the region.

Certain faults are supposed to occur in connection with the boundaries of the Triassic both in Connecticut and Massachusetts, principally in connection with the eastern boundary, and they have been indicated on the map[b] accompanying the report of Professor Davis.

JOINTING.

Jointing in traps.—Besides the faults there are certain minor lines of regular separation which demand attention. These are the joints which exist in great numbers throughout the mass. Every trap ridge in the lowland shows them in a remarkable degree, but they are especially prominent in the mountains of the main range. The trap sheets are divided by a vast number of these joints, the planes of which run in a direction generally perpendicular to the cooling surface, and along these planes the rock splits up into approximately rectangular blocks of all imaginable sizes. It is these joint planes that form the nearly vertical western faces of the mountains, and in cases where erosion, working on some local fault, has produced an escarpment facing eastward, the cliffs actually overhang. Every trap eminence of any considerable height is fronted by a long talus of broken trap, formed of joint blocks of all sizes which have fallen down from the cliffs above. A little gorge marking the line of a small fault near the crest of West Peak is fairly choked with slabs, some of them 12 feet square and several feet thick, which have been derived from the walls of the gorge. On the top of Rattlesnake Mountain are large blocks of trap that have been detached along joint planes, while at the foot of Talcott Mountain, on the line of the old Albany turnpike, lies a joint block as large as a small house. The blocks range from this size down to an inch square. In some localities the joints divide the trap into sheaves of blade-shaped fragments.

Jointing in sedimentary rocks.—Jointing in the sedimentary beds does not reach the highly developed condition seen in the trap sheets. In the heavy sandstones at the great brownstone quarries at Portland the joints are on a large scale and are indispensable aids in separating the great blocks of building stone. Yet here these lines of fracture are potential rather than actual. In the shales the joints become much more numerous and may be regarded as universal. In the city stone pits near Trinity College at Hartford the Posterior trap has been removed for road metal, leaving broad sheets of Posterior shale, marked with ripple marks and mud cracks, exposed to view. One looking down upon this floor from the top of the cliff may see two sets of joint cracks that cross each other at an angle of about 60 degrees and divide the mass into lozenge-shaped sections. Working along these two sets of joint planes and the plane of the bedding, the quarrymen remove blocks of shale averaging about a foot square and 6 to 8 inches thick, which are used as the foundation rock in the construction of the streets. Joint blocks in this shale may be extremely variable in size, and are often not over an inch in any dimension. An examination of almost any mass of shale throughout the lowland will show that the jointing seen in this quarry is typical.

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[a] Emerson, B. K., Geology of old Hampshire County, Massachusetts: Mon. U. S. Geol. Survey, vol. 29, Pl. XXXIV.

[b] Davis, W. M., The Triassic formation of Connecticut: Eighteenth Ann. Rept. U. S. Geol. Survey, Pl. XIX.

Although jointing in the sediments does not produce such striking results as in the trap, yet the joints themselves extend, the writer believes, to much greater distances, both vertically and horizontally, in the sedimentary than in the igneous rocks. Apparently they frequently become actual fissures in the deep rocks and have a profound effect on the water supply, as will be shown later.

GLACIAL AND RECENT DEPOSITS.

The entire Triassic area has been subjected to the action of the ice sheets that passed over the region in Pleistocene times. The outlines of the harder ridges have been softened and the softer rocks have been worn away in many places by the scouring action of the ice. Deposits of till were formed beneath the sheet and now remain in the shape of the well-known hardpan, while gravel and sand deposits were formed as terraces or valley fillings by the glacial streams throughout the region. Since these deposits were laid down much material has been carried from them by streams and redeposited to form the present flood plains.

The presence of drift over the region is of great importance to the water supply. If the bare surfaces of the rocks were exposed the water would run off rapidly instead of being absorbed, but the glacial deposits, especially the sands and gravels, hold in storage large quantities of water, which is thus kept in contact with the underlying sandstones, by which the water is continually being absorbed.

WELLS OF THE CONNECTICUT VALLEY LOWLAND.

Although there are few flowing wells in the Triassic area there are many wells from which water is pumped, and some of these would yield a supply much in excess of the capacity of the pumps that are used in them.

In the description of wells which follows an attempt is made to present data bearing upon the occurrence, volume, and quality of the water. Most of the records were gathered several years ago, but the area is fairly well covered and the information is comprehensive. In interpreting the figures due weight should be given to the source of information. Depths reported by drillers are likely to be more accurate than those furnished by owners, but on the other hand the quantity is more likely to be accurately stated by the owner. The reports of both owner and driller as to quality are likely to be more optimistic than the facts warrant, but the use to which the water is put—or, better, the uses to which it is not put—usually gives a clue to its actual character.

The records are far from uniform in the character of the points presented, certain features that are of special interest and consequence in one well being of little interest in another, which may show an entirely different set. The greater abundance of the records in the vicinity of the towns along the center of the area makes the data in such situations more complete than for the outlying portions, but the value of the data presented for wells in the outlying regions is probably greater. Data relating to wells that were failures are especially difficult to obtain from either owner or driller. The driller especially is loath to give details which might tend to discourage further drilling. This is unfortunate, as perhaps fully as much information as to the actual underground conditions is afforded by the dry holes as by the successful wells.

WELLS ENTERING THE ROCK.

The typical wells of this area are those which are sunk for the greater part of their depth in the rock, but a short list of wells of the drift, including those which lie in unconsolidated deposits, generally of glacial origin, overlying the Triassic rocks is also given. Certain of these wells are distinctly interesting, as their water supply seems to depend not on the arrangement of the deposits in which they are located, but on the conformation of the surface of the rocks which lie below.

WELLS IN MASSACHUSETTS.

NORTHAMPTON.

No. 1. Belding Brothers' Silk Company.—This well is in its way the most remarkable in the valley, as it was carried to the great depth of 3,700 feet without striking water. Mr. E. F. Crooks, writing for the company, states that at the "depth of 150 feet the drill entered sandstone or conglomerate rock which did not change at any time down to 3,700 feet." Professor Emerson classes the rocks which underlie Northampton as Sugarloaf arkose and gives a list of the beds traversed in drilling this well.[a] It seems probable that this well was driven through a water-bearing stratum at the point where it enters the rock, since a shallower well sunk by the same company to the rock, within a few feet of the former well, draws good water from that depth. This second well will be referred to again among the wells of the drift. The dry well is 8 inches in diameter.

SOUTH HADLEY FALLS.

No. 2. Sans Souci Club.—At the clubhouse of this organization is a private well 74 feet deep and 6 inches in diameter, entering the Longmeadow sandstone at a point 10 or 15 feet below the surface of the ground. The water, which is of medium hardness, supplies all needs of the clubhouse. The well is pumped.

HOLYOKE.

Nos. 3 and 4. American Writing Paper Company (Albion Paper Company Division).—These two wells, which are identical in detail, are 720 feet deep and have a diameter of 8 inches. The water rises within 14 feet of the surface, from which point it is pumped. Each well yields 450 gallons a minute throughout the twenty-four hours of the day, the water being slightly tinged with iron and not used in boilers. The wells enter the Chicopee shale about 50 feet below the surface.

No. 5. Holyoke Cold-Storage and Provision Company.—This well is over 500 feet deep, has a diameter of 3½ inches, and has its bottom in the Chicopee shale. The water, which has been analyzed, can be used in boilers, but is employed mostly for refrigerating purposes. The water is pumped at the rate of 20 to 25 gallons a minute.

No. 6. Riverside Paper Company.—A well, concerning which no data could be obtained, was drilled by this company, but was abandoned because of the mineral matter contained in the water.

WILLIMANSETT.

No. 7. Hamden Brewing Company.—This well is 112 feet deep and has a diameter of 4 inches. It is sunk partly in rock, which is apparently Chicopee shale. The well is pumped at the rate of 60 barrels an hour—that is, about 40 gallons a minute—without lowering the level at which the water stands. The water has been analyzed and is too hard to be used in boilers.

LUDLOW.

No. 8. Ludlow Manufacturing Company.—This well is 150 feet deep and has a diameter of 8 inches for the first 50 feet, below which it is reduced to 6 inches. After passing through 6 feet of made land the well lies for the rest of its depth in rock, which is mapped as Sugarloaf arkose. The water level is about 21 feet below the surface, but, when the well is pumped at the rate of 20 gallons a minute, the level drops to a point 20 feet lower. The water is called medium hard, but can not be used in boilers.

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[a] Emerson, B. K., Geology of old Hampshire County, Massachusetts: Mon. U. S. Geol. Survey, vol. 29, 1898, pp. 385-388.

CHICOPEE FALLS.

No. 9. Overman Wheel Company.—This well is 475 feet deep and 6 inches in diameter, the lower 175 feet lying in the Chicopee shales. The well was drilled to obtain water for drinking purposes only and it supplied all the employees of the big establishment abundantly. It was found, however, that the water was so full of mineral matter that it had a purgative effect on those who drank it and now its use is wholly discontinued. The water has been analyzed.

BRIGHTWOOD.

No. 10. Springfield Rendering Company.—This well was unfinished when the locality was visited in July, 1900. It was drilled by Messrs. King & Mather, of Hartford, who very kindly furnished the data concerning it on the completion of the work, a few weeks later. The well is 200 feet deep and has a diameter of 6 inches. It pumps 150 gallons a minute and meets the demands made upon it—90,000 gallons for a working day of ten hours. The water when analyzed proved to be sufficiently pure for use in boilers. It is sunk 59 feet through earth, the remainder being in the Chicopee shale.

Nos. 11 and 12. Springfield Provision Company.—This company has two wells, concerning which there is some uncertainty as to depth and diameter. They are only a few hundred feet south of the well just mentioned, and it is a matter of no small interest to note the great difference in the character of the water. Well No. 11 has a depth of 160(?) feet and a diameter of 6(?) inches, and pumps 150 gallons a minute without being pumped dry. No. 12 has a depth of 300(?) feet and a diameter of 6(?) inches, pumps 300 gallons a minute, and has never failed. Both wells enter the Chicopee shale at a depth of 60 feet. The water of these wells has been analyzed. It is too hard for boilers, and can not even be used for drinking, because of the mineral matter it contains.

SPRINGFIELD.

No. 13. Springfield Cold Storage Company.—This well is 325 feet deep and 8 inches in diameter, 290 feet of its depth lying in the Chicopee shale. The company has also a shallower well, 35 feet deep, which would bring it down to the surface of the rock. The two wells together yield 30 gallons a minute to the pump. The water is not fit for boilers, and is used only for condensing purposes.

Nos. 14, 15, and 16. Springfield Brewing Company.—No. 14 is 100 feet deep and 4 inches in diameter. The pump renders 150 gallons a minute. The analysis shows that the water carries considerable mineral matter.

No. 15 is identical in every respect with No. 14.

No. 16 is 300 feet deep, 4 inches in diameter, and yields only 60 gallons a minute. The water is poor in quality, and is used only for washing purposes.

All of these wells are pumped. The water is not used for boilers as the city water, which is very satisfactory, is already in use. Wells Nos. 14 and 15 go only to the rock, and are therefore to be reckoned among the wells of the drift, under which head they will be mentioned again.

No. 17. Morgan Envelope Company.—This well was originally 212 feet deep and flowed at the surface at the rate of 7 gallons a minute. It was afterwards sunk to 325 feet, but there was no gain in the supply. A deep-well pump was then put in at a depth of nearly 200 feet, and a supply of 25 gallons a minute is now obtained. The well runs for "60 feet through dirt, clay, hardpan with gravel," and then for "265 feet in sandstone rock." This rock is apparently the Chicopee shale. The water has been analyzed and proves to be a very good drinking water, though hard. In a working day of 10 hours from 5,000 to 6,000 gallons are commonly used. The diameter of the well is 6 inches.

No. 18. Kibbe Brothers Company, candy manufacturers.—This well is 252½ feet deep, 6 inches in diameter, and pumps 25 gallons a minute—the capacity of the pump. An analysis of the water made at Amherst College showed that it contains only a small amount of solid matter. It is not used for boilers, but is employed in the making of candy and for drinking purposes. The well runs first through about 40 feet of clay, the balance being in "sandstone"—probably Chicopee shale.

No. 19. Fiske Manufacturing Company.—The well of this company is 365 feet deep and 4 inches in diameter. It is pumped, but the amount of water obtained is unknown. The water has been analyzed and is not used in boilers. About two-thirds of the well lies in rock, probably the Chicopee shale.

Though the map indicates that many of the foregoing wells are sunk in the Chicopee shale, they nevertheless lie very close to its contact with the eastern area of Longmeadow sandstone.[a] This will perhaps account for the "sandstones" noted in the original records furnished.

Nos. 20 and 21. Highland Brewing Company.—These wells are used by the Highland branch of the Springfield Breweries Company. No. 20 is 424 feet deep, of which about 365 feet are in rock. Its diameter is 10 inches. It pumps 80 gallons a minute, the water rising to within 30 feet of the surface.

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[a] See map accompanying Professor Emerson's monograph.

No. 21 is 200 feet deep, of which about 160 feet are in rock. Its diameter is 8 inches. It pumps 60 gallons a minute, the water rising to within 15 feet of the surface.

Both of these wells yield water of excellent quality, which can be used in boilers. The brewery stands upon the terraces lying east of Connecticut River and in consequence is about 100 feet above the level of the Springfield wells previously mentioned, which are pretty close to the east bank of the river. The rock underlying this portion of the town is mapped by Professor Emerson as Longmeadow sandstone.

No. 22. Joseph H. Wesson, 13 Federal street.—This well is 276 feet deep and 6 inches in diameter. No estimate could be obtained of the quantity yielded, except that the pump would "furnish a 1-inch stream constantly." "The water is used only for drinking, but is pronounced good for boilers by Professor Wood, of Harvard." One hundred and fifty-one feet of the well lie in rock which is presumably Longmeadow sandstone.

Professor Emerson's monograph[a] contains a number of valuable items concerning the water supply of the Triassic area. Notes relating to several of the wells mentioned by him are subjoined.

OTHER WELLS IN TRIASSIC AREA IN MASSACHUSETTS.

No. 23. Daniel Brothers' paper mill.—This mill is on Westfield Little River, south of Westfield. The well was carried to a depth of 1,100 feet, but proved unsuccessful and is now closed up.[b] The rock at this locality is Sugarloaf arkose. It is an interesting and suggestive fact, as has been remarked before, that the only wells in the lowland which have been carried to exceptional depths, merely to meet with failure, have been sunk in this rock.

No. 24. Mount Holyoke College, South Hadley.—This well was carried to a depth of 450 feet in Longmeadow sandstone, the full record of the borings being given by Professor Emerson.[c] The water, when analyzed, was found to contain common salt in large amount.

No. 25. Montague Paper Company at Turners Falls.—This well was carried to a depth of 875 feet in Longmeadow sandstone. The record of the borings is given by Professor Emerson.[d] The appended analysis of a sample from the well shows that the water has nearly the composition of bittern.[e]

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[a] Mon. U. S. Geol. Survey, vol. 29.

[b] Ibid., p. 389.

[c] Ibid., p. 382.

[d] Ibid., pp. 380-381.

[e] Ibid., p. 750.

Analysis of deep well water at Turners Falls, Mass.

[C. A. Goessman, analyst, 1874.]

	Parts per million.
Potassa	6
Soda	51
Magnesia	63
Lime	633
Chlorine	6
Sulphuric acid	996
Silicon	Trace.
Total	1,755

Other wells.—Other wells mentioned are two of the Parsons Paper Company, of Holyoke, which reached depths of 510 feet and 685 feet, respectively.[a]

WELLS IN CONNECTICUT.

THOMPSONVILLE.

No. 26. Connecticut Valley Brewing Company.—This well is 52 feet deep and 6 inches in diameter, having 40 feet of its depth in the rock. The water rises within 7 feet of the top, a good many feet above the level of the Connecticut River, which is only a stone's throw away. The pump raises 31 gallons a minute, which lowers the well 8 feet, but no farther. The water is moderately hard, has been used in boilers, and keeps a uniform temperature of 51° F. the year round.

No. 27. Isaac Allen, Enfield street.—This is a private well, 67 feet deep and 6 inches in diamater. It is sunk 50 feet in rock, the last 5 feet, it is said, being in granite—a manifest impossibility. Mr. Allen states that a spring of soft water was struck at a depth of about 45 feet and a spring of hard water at the bottom, the mixture making an excellent drinking water. The well furnishes more than double the quantity of water that can be used in house and barn. The water is 45 feet deep in wet weather and 30 feet in dry. The temperature is 52° F.

SUFFIELD.

Nos. 28 and 29. Town water supply of Suffield.—These wells are owned by Paulus Fuller. No. 28 is 230 feet deep and has a diameter of 6 inches, and No. 29 is 240 feet deep and has a diameter of 8 inches. These two wells together pump at the rate of 300 gallons a minute into a standpipe containing 293,000 gallons. The water rises within about 60 feet of the surface and is rather highly mineralized. It can be used in boilers, however, but gives some scale. The wells enter rock about 10 feet below the surface of the ground.

No. 30. Public well, Suffield Village.—The depth of this well is 140 feet and its diameter is 6 inches. The water stands about 90 feet below the surface and is raised by a common force-pump. It is used for drinking purposes only.

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[a] See Mon. U. S. Geol. Survey, vol. 29, pp. 383-385, where a full record of the borings is given.

Additional Suffield wells.—The wells tabulated below are 6 inches in diameter and are in greater part in rock. The data were furnished by Mr. C. L. Grant, well driller.

Serial No.	Owner.	Depth of well.	Depth of water.	Yield per minute.
		Feet.	*Feet.*	*Gallons.*
31	F. A Fuller	40	34	8
32	A. C. Harmon	45	39	3
33	Second Baptist Church	60	47	4
34	M. T. Newton	63	49	10

WEST SUFFIELD.

No. 35. West Suffield Hotel.—This well is 78 feet deep and 4 inches in diameter, and pumps 50 gallons of moderately hard water a minute. The water is said to have grown harder since the well was sunk. About 50 feet of the well is in rock.

No. 36. Mrs. John D. Loomis.—Depth, 100 feet; diameter, 4 inches; yield, 4 to 5 gallons a minute. Almost no water was found until a depth of nearly 95 feet was reached.

TARIFFVILLE.

No. 37. A. B. Hendryx.—Depth of well, 284 feet; depth of water, 278 feet; yield, 48 gallons a minute. Greater part of well is in rock. Data furnished by C. L. Grant, well driller, of Hartford.

BLOOMFIELD.

No. 38. Douglas & Cowles.—Depth, 100 feet; diameter, 6 inches. Well flows at the surface. Greater part of well is in rock. No data of yield given. Data furnished by Grant.

WINDSOR.

No. 39. Windsor Water Company.—Depth of well, 386 feet; depth of water, 326 feet; diameter, 6 inches. The pump yields 30 gallons a minute, which lowers the water 5 feet. The series through which the well was sunk is as follows: Sand, 17 feet; clay, 56 feet; hard red gravel, 50 feet; the remainder in sandstone with the exception of two layers of slate. Four analyses of the water have been made, according to which it ranges from moderately hard to excessively hard. It would seem that the water is extremely free from organic impurities, but shows sulphate of lime to the extent of 590 parts to the million.

It is extremely hard to the soap test. When first drawn the water is said to give off a strong odor of sulphur.

No. 40. Christianson Brothers, Wilson Station.—Depth, 113 feet; diameter, 6 inches; yield, 50 gallons a minute. The well was drilled in the bottom of an old open well and lies in the rock. The water is good only for drinking and garden use. It is said that when the well was first drilled the water had a very strong odor, which disappeared after the well had been used a while. Data furnished by King and Mather.

No. 41. Misses Crompton, Windsor Heights.—One hundred and forty feet deep, but of small diameter. The water, which is raised by a pump, is of medium hardness. About 500 gallons per week is the ordinary consumption. The bottom of the well is in rock.

No. 42. Dr. H. J. Fisk, Windsor Heights.—About 135 feet deep and of small diameter. The water is pumped and hardly supplies the needs of the house and barn. It is of medium hardness, much softer than that of the neighboring surface well. The well was originally 85 feet deep, but was always more or less turbid. It was then deepened and the trouble disappeared. It enters the rock. For analysis see No. 7, table on pages 108–109.

No. 43. C. D. Reed.—Depth of well, 101 feet; depth of water, 89 feet; diameter, 6 inches; yield, 25 gallons a minute. Greater portion lies in rock. Data furnished by Grant.

HARTFORD.

No. 44. Hubert Fischer Brewing Company.—This well is 500 feet deep and has a diameter of 8 inches. The water rises to the surface of the engine-room floor, and is pumped at the rate of 75 gallons a minute. There is a difference of opinion as to whether the water is suitable for boilers. The well is drilled in the Upper sandstones, but unquestionably pierces the Posterior trap sheet, which outcrops at no great distance to the west.

Nos. 45, 46, 47, 48, and 49. Hartford Light and Power Company.—The wells of this company all lie in the rock. The data were furnished by Mr. Grant, who drilled them.

Data concerning wells of Hartford Light and Power Company.

Serial No.	Depth.	Yield per minute.
	Feet.	*Gallons.*
45	200	120
46	228	150
47	201	120
48	200	150

The above wells are all 6 inches in diameter. The deeper well described below has greatly diminished the supply of the earlier wells enumerated above. The data concerning this fifth well (No. 49) are as follows:

Depth, 620 feet; diameter, 12 inches. The meter has shown a capacity of 125 gallons a minute. The well is pumped and gives a more copious supply of water in rainy weather than in dry. The water is very hard from sulphate of lime and can not be used in boilers, but is employed for condensing. The well lies in rock. These wells are said to have seriously depleted the supply of water in the well of the neighboring Plimpton Company.

No. 50. Capewell Horsenail Company.—This well was drilled by Mr. C. L. Grant, who furnished the following data: Depth, 250 feet; diameter, 8 inches. The well is in rock and flows. Elisha Gregory, a well driller of New York City, states in his "Torpedo Circular" that the well was torpedoed by him at a latter date and that as a result the yield of the well was increased from 15 gallons a minute to 35 gallons. It is reported that the quality of the water was injured by the process. Inquiry at the office of the company shows that at last accounts the water was not used for anything, so heavily is it charged with mineral matter. For analysis see No. 3, table on pages 108–109.

No. 51. Patten's dyeing and carpet-cleaning establishment.—Depth, 110 feet; diameter, 6 inches; yield, 150 gallons a minute (data furnished by Grant). The amount which is ordinarily pumped is about 70 gallons a minute. The well lies in the rock. The water is unfit for boilers.

No. 52. Ropkins & Company, brewery.—Depth, 200 feet; diameter, 6 inches; yield, 60 gallons a minute (data by Grant). The ordinary yield of the well is 25 gallons a minute and it flows if left standing. The water is too hard for boilers.

No. 53. New England Brewing Company.—Depth, 462 feet; diameter, 10 inches. The ordinary yield to the pump is 350 gallons a minute, but 400 gallons a minute have been pumped without making any apparent impression on the well. The water is too hard for boilers.

No. 54. Columbia Brewing Company—This was formerly the Herold Capitol Brewing Company. Depth, 300 feet; diameter, 6 inches; yield, 250 gallons a minute (data by Grant). The amount of water pumped for common use is about 80 to 90 gallons a minute. The water is too hard for boilers.

No. 55. Armour & Company.—Depth below grade, 436 feet; actual depth below floor of basement, 420 feet; diameter, 6 inches. The water flows about 1 inch over the top of the pipe when allowed to stand, which brings the water level above the surface of a large part of the neighboring land. The ordinary yield is about 150 gallons a minute throughout the twenty-four hours, but a much larger yield could be obtained if desired. At the time these data were obtained no report had been received on the sample of water sent for analysis.

No. 56. Long Brothers hotel.—Depth, 200 feet, of which 186 feet are in the rock. Diameter of the portion which is in the rock, 6 inches. The well is pumped and yields a maximum supply of 35 gallons a minute. The water is too hard for boilers or for laundry work, but it is claimed that its quality is steadily improving.

No. 57. Brady Brothers, bottlers.—Depth, 277 feet, of which 244 feet lie in the rock. Diameter, 6 (?) inches. The well will yield 25 gallons a minute, but the amount usually pumped is 9 gallons a minute. The water has never been tried in boilers, but is used for making all kinds of soft drinks. At times it becomes clouded, but in a few days it clears again.

The above data were obtained from Brady Brothers.

No. 58. Brady Brothers.—Mr. Grant reports the following data concerning a well drilled for Brady Brothers, which is probably another than the one just described: Depth, 159 feet; diameter, 6 inches; yield, 29 gallons a minute.

No 59. "Allyn House."—Depth, 318 feet, of which 288 feet are in rock. Diameter, 4½ inches; yield, 60 gallons a minate. The ordinary consumption for eighteen hours is 30,000 gallons. The water, which has been analyzed, is too hard for boilers, but has improved in quality with time

No. 60. W. C. Wade, corner State and Front streets.—Depth, 125 feet, of which 113 feet are in rock. The maximum yield is 200 gallons a minute, though only 50 gallons a minute are in common use, chiefly for refrigerating purposes. The water, which rises to within 13 feet of the surface, is a little too hard for boilers. Its summer temperature is 54° F.

No. 61. W. C. Wade, "Public Market."—Mr. Grant sends data of a well drilled for Mr. Wade at the "Public Market," about one-third of a mile from the well above mentioned, as follows: Depth, 225 feet; depth of water, 183 feet; yield, 28 gallons a minute.

No. 62. Keney Park.—Depth, 200 feet; diameter, 6 inches. The well flows, but the yield was not given. Data by Grant.

No. 63. Keney Park.—Depth of well, 170 feet; depth of water, 138 feet; yield, 5 gallons a minute. Data by Grant.

Other wells in Hartford.—The following list of wells in Hartford was obtained from Mr. Grant. The wells are all 6 inches in diameter and have the greater part of their depth in rock.

Additional wells in Hartford.

Serial No.	Owner.	Depth of well.	Depth to water.	Yield per minut
		Feet.	*Feet.*	*Gallons.*
64	F. C. Rockwell	115	111	60
65	E. C. McCune	110	87	18
66	Frank S. Tarbox	57	48	5
67	.....do	67	56	3
68	T. C. Moore	60	40	3
69	G. E. Hubbard	37	37	8
70	.....do	62	40	12
71	St. Mary's Home	100	97	15
72	Walter S. Mather	37	37	3
73	J. Dart & Son	24	12	3
74	.....do	74	Flows.	22
75	Hotopp & Carlsson	155	130	10
76	Wm. O'Brien	50	30	11
77	Addison & Impey	63	36	5
78	Johnson & Weeks	49	29	10
79	Wm. Rogers	110	35	5
80	Peter Peterson	50	40	3
81	A. Hepburn	50	39	5
82	C. L. Bailey	48	27	12
83	H. J. Abbey	35	18	3
84	Andrew Nason	28	16	4
85	B. L. Chappell	50	34	4
86	G. E. Hurd	50	39	4
87	M. H. Ericksen	37	24	10
88	O. W. Crane	60	30	2
89	C. A. Green	50	38	3
90	J. C. Parsons	136	86	1
91	O. Bengston	50	25	10
92	F. H. Seymour	70	40	8
93	G. J. Maher	65	47	11
94	A. M. Weber	75	50	5
95	D. F. Keenan	140	111	10
96	The "Linden"	240	215	45
97	Hartford Woven Wire Mattress Co	246	230	10

WEST HARTFORD.

No. 98. H. O. Griswold.—Depth, 152 feet; diameter, 6 inches. The water has been analyzed, and contains three times as much lime as is desirable in drinking water. In consequence it is very hard and is used very little. The ordinary depth of the water is 137 feet, but it has been lowered by pumping to within 40 feet of the bottom. The well runs through loam and hardpan for 10 feet, the balance being in rock.

Other wells in West Hartford.—The following supplementary list is furnished by Mr. Grant. All the wells are 6 inches in diameter, except No. 101, which is 4 inches.

Additional wells in West Hartford.

Serial No.	Owner.	Depth of well.	Depth to water.	Yield per minute.
		Feet.	*Feet.*	*Gallons.*
99	Paul Thomson	40	18	12
100	James Thomson	110	95	35
101	E. C. Wheaton	135	115	34
102	Mrs. K. Gallagher	53	44	2½
103	G. V. Brickley	30	15	12
104	W. E. Howe	62	18	2
105	H. C. Long	41	25	12
106	L. N. Burt	52	39	4
107	P. H. Reilly	206	160	42
108	D. F. Crozers	101	87	32

Well No. 107, which is in the trap, lies on the ridge south of the village of West Hartford. The trap belongs to the Posterior sheet, and is comparatively thin. The thickness of the trap at this point has not been determined, but at least two-thirds, and possibly three-fourths, of the depth of the well must be in the Posterior shales which underlie the sheet. On comparing this depth with the depth of water in the well, it will be readily seen that it is very probable that the water does not come from the trap at all, but from the underlying shale. In consequence the well can not with propriety be classed as a well of the trap.

BURNSIDE.

No. 109. East Hartford Manufacturing Company.—Depth of well, 398 feet; diameter, 6 inches. No estimate of the yield in gallons could be obtained, but the well is said to flow constantly 1 inch deep over the top of a 10-inch pipe. If this statement is correct, this is the largest flowing well in the lowland. The water has been analyzed by Springfield chemists and found to carry considerable mineral matter, and is too hard for boilers. The well is entirely in rock.

No. 110. J. H. Walker, paper mill.—The water of the well is excellent for drinking, but hard. Measurement showed the well to be pumping 8 to 10 gallons a minute. As it is separated from the last-mentioned well only by the breadth of the Hockanum River, the rock conditions are probably the same as in that well.

SOUTH MANCHESTER.

M. S. Chapman.—These are four private wells, each 6 inches in diameter, used, as I understand, to supply fish ponds. Their depths and the amounts of water they yield are shown below:

Wells of M. S. Chapman.

Serial No.	Depth.	Yield per minute.
	Feet.	*Gallons.*
111	225	30 to 40
112	125	10 to 12
113	75	2½
114	75	None.

The wells enter the rock at a depth of 20 feet, and the first three flow at the surface of the ground. The water is of good quality and, it is said, can be used for any purpose, although it is distinctly hard by the soap test.

No. 115. Cheney Brothers, silk manufacturers.—This is one of the most remarkable wells in the lowland, and the data concerning it have been carefully preserved. The well is 457 feet deep, and its diameter is 8 inches for the first 383 feet, below which it is only 6 inches. The well flows at the surface at the rate of 250 gallons a minute, while the experiment of pumping 650 gallons a minute for ten consecutive minutes lowered the water level only 10 or 12 feet below the surface. The water is unfortunately very hard, but the well is used to its full capacity in washing colored silks, the water of the well remaining at the proper temperature summer and winter. Below the first 12 feet the entire well is in red sandstone. For analysis see No. 6, table on pages 108–109.

NORTH MANCHESTER.

No. 116. F. J. Sharp.—Depth of well, 100 feet; depth of water, 99 feet; diameter, 6 inches; yield, 10 gallons a minute. The water has been analyzed and proves to be very hard. Eighty-one feet of the well lie in red sandstone.

No. 117. American Writing Paper Company (Oakland Paper Company division).—Depth, 300 feet; diameter, 4 (?) inches. The water flows over the top of the pipe at a rate of probably 10 to 12 gallons a minute. The water is hard and is used for drinking purposes only. The well lies entirely in the rock, which, in the stream near by, is seen to be rather loose in texture and to be filled with fragments of the crystalline rocks of the neighboring eastern upland.

The wells east of Hartford along the Valley of Hockanum River, comprising Nos. 109 to 117, inclusive, all flow at the surface of the ground, except No. 114, which is dry, and No. 116, which rises to within 1 foot of the surface. In general the yield of these wells is exceptionally large, but the water is uniformly hard.

WETHERSFIELD.

The following data were kindly furnished by Mr. Grant concerning wells at this place.

Wells in Wethersfield.

Serial No.	Owner.	Depth of well.	Depth to water.	Yield per minute.
		Feet.	*Feet.*	*Gallons.*
118	J. H. Rabbett	30	28	8
119	Rev. Lynch	70	40	35
120	C. I. Allen	192	85	15

No. 120 is in trap rock. All are 6 inches in diameter.

ROCKY HILL.

No. 122. W. E. Pratt.—This well is located in the thin posterior sheet of trap. It was drilled in the bottom of an old open well, 20 feet deep, which entered the rock for a distance of 6 feet. From this point the well was drilled 30 feet through trap when it broke into the underlying sedimentaries, which it pierced to the depth of 1½ feet. This well therefore gives a section of 14 feet of soil, 36 feet of trap, and 1½ feet of sedimentary rock—a total depth of 51½ feet. This brings the bottom of the well about 50 feet above the surface of Connecticut River, which flows by it only a few hundred feet eastward. The diameter of the well is 6 inches and the maximum amount of water obtainable is a little less than 1 gallon a minute. The well pumps dry in thirty minutes. The water is fair for drinking, but is excessively hard.

No. 123. J. K. Green.—Depth of well, 26 feet; depth of water, 25 feet; diameter, 6 inches; yield, not given. The well is in trap rock. Data by Grant.

KENSINGTON, BERLIN JUNCTION.

No. 124. New York, New Haven and Hartford Railroad power house.—Depth, 300 feet; diameter, 6 inches; yield, 120 gallons a minute. Data by Grant. Water is raised by a common pump. It is permantly hard and unfit for boilers.

Wells at Berlin and Berlin Junction.—The following list of wells at Berlin and Berlin Junction was furnished by Mr. Grant. All are 6 inches in diameter.

Additional wells at Berlin and Berlin Junction.

Serial No.	Owner.	Depth of well.	Depth to water.	Yield per minute.
		Feet.	*Feet.*	*Gallons.*
125	Berlin Brick Co	60	49	....
126	.....do	70	62	....
127	Yale Brick Co	100	81	10
128	F. L. Wilcox	71	40	....
129	J. B. Smith	200	130	6

NEW BRITAIN.

No. 130. Hotel Russwin.—The depth of the well is 152 feet, and the depth of the water at the lowest 130 feet, but if the well is allowed to stand the water flows at the level of the engine-room floor, which is 10 feet below grade. The ordinary consumption is fully 10,000 gallons a day. The water is very pure and can be used for all purposes. Certain features of this well which have a distinct bearing on the theory of underground flow will be considered in connection with the discussion of that subject.

Other wells.—The following list is from Mr. Grant:

Additional wells at New Britain.

Serial No.	Owner.	Depth of well.	Depth to water.	Yield per minute.
		Feet.	*Feet.*	*Gallons.*
131	Dennis & Co	195	....	40
132	A. J. Sloper	70	....	45
133	A. B. Johnson	60	....	12
134	W. E. Bradley	40	22	4
135	J. P. Curtis	250	237	12
136	William Derby	50	31	6
137	F. B. Wischek	50	38	6

Nos. 132 and 134 are sunk in the trap of the Posterior sheet and may lie entirely in volcanic rock. All the wells are 6 inches in diameter.

CROMWELL.

Nos. 138 and 139. New England Brownstone quarry.—The wells are 63 feet and 132 feet deep, respectively. The water, which was raised with a pump, was thoroughly tried in the boilers and was found totally unfit for the purpose.

MIDDLETOWN.

No. 140. Goodyear Rubber Company.—The well, which is 384 feet deep and 6 inches in diameter, pumps about 40,000 gallons in twenty-four hours, or nearly 30 gallons a minute. The water is called good, but has not been tried in the boilers on the ground that it would probably prove too hard. It is reported that the well flows at the surface. For analysis of water from a Middletown well, see No. 9, table on pages 108–109.

MERIDEN.

Nos. 141–145. Edward Miller & Co.—There are on the premises of this company five artesian wells, all 8 inches in diameter, ranging from 250 to 300 feet deep, and bored into red sandstone rock, which at this place lies from 6 to 10 feet below the surface of the ground. The output of these wells was measured when they were first bored and varied in the different wells from 10 to 80 gallons per minute. The supply thus measured was obtained by means of an ordinary suction pump, which, operated at the rate named, lowered the water about 25 feet below the surface—as low as it could be pumped with that form of apparatus. A few years ago the Pohle air system was installed for raising the water from the wells. This system works by compressed air and forces the water from depths of 70 to 90 feet. With this apparatus a very greatly increased output was obtained, which now supplies all the needs of the company. The water from these wells is all discharged into one large system, from which it is circulated through the factory. It is not easy to determine exactly the amount of water used, but by estimate it is between 75,000 and 100,000 gallons a day of ten hours. There is no doubt a much larger quantity than this could be obtained if needed. The water is satisfactory for all manufacturing purposes except for making steam, for it holds considerable mineral matter in solution and is rather hard for use in boilers.

No. 146. Foster, Merriam & Co.—The well is 300 feet deep, 200 feet of which are in rock. The well flows at the surface if allowed to stand, and pumps, at the maximum, 10,000 gallons an hour—about 170 gallons a minute. The water is too hard for boilers and contains a certain amount of sand. The outer pipe is 8 inches in diameter and the inner 6 inches.

No. 147. International Silver Company, Factory "E" (Meriden Britannia Company).—Depth of well, 560 feet; depth of water when the well is not pumped, 555 feet; diameter, 6 inches. No data of yield could be obtained. The water is very hard and wholly unfit for boilers. The section traversed in drilling is as follows: Soil, 9 feet; gravel, 18 inches; quicksand, 90 feet; balance mostly rock.

No. 148. Meriden Curtain Fixture Company.—Depth, 305 feet; diameter, 6 inches. The amount of water in common use for a working day of 10 hours is 15,000 gallons, or about 25 gallons a minute. The water is suitable for use in boilers. About 255 feet of the well are in rock.

WELLS AT OTHER PLACES IN NEW HAVEN COUNTY, CONN.

The following data, which have been put in tabular form, were received from Mr. Grant:

Additional wells of Connecticut Valley.

Serial No.	Town.	Owner.	Depth of well.	Depth to water.	Yield per minute.
			Feet.	*Feet.*	*Gallons.*
149	Yalesville	G. I. Mix & Co	100	....	40
150		J. H. Yale	67	22	3
151		C. W. Michaels	90	72	....
152	West Cheshire	Cheshire Manufacturing Co.	150	....	100
153	Mount Carmel	Chas. Wheeler	50	17	6
154		Sylvester Peck	36	21	5
155		H. D. Clark	60	Flows.	22
156	Quinnipiac	C. T. Stevens	40	Flows.	4
157	North Haven	F. L. Stiles	83	....	35
158		I. L. Stiles & Son	102	....	30
159		H. P. Smith	116	100	18
160		N. W. Hine	125	115	16
161	Whitneyville	H. Stadtmiller	85	58	5
162		J. H. Burton	50	40	22
163		W. F. Downer	67	40	5
164		W. F. Downer	50	42	7
165		Edward Davis	56	47	11
166		Edward Davis	13	11	20
167		G. W. Ives	65	52	8
168		Mr. Brock	50	35	24
169		Mr. Johnson	58	33	25
170		W. Mansfield	48	37	....

These wells are all 6 inches in diameter, and probably all of them enter rock, except, possibly, No. 166.

NEW HAVEN.

No. 171. Hoyt Beef and Produce Company.—Depth, 600 feet, of which 200 feet only are in rock; diameter, 6 inches. The well flows at the rate of 3 gallons a minute, yielding water of very good quality which has not been analyzed.

No. 172. Lavigne Automatic Machine Company.—Depth, 95 feet; diameter, 6 inches; yield, 12 to 15 gallons a minute. The data concerning the quality of the water seem to be favorable in a general way. The well passes through 53 feet of quicksand and 42 feet of red sandstone.

No. 173. New England Dairy Company.—Depth about 160 feet; diameter of outside pipe 6 inches, and of inside pipe 4 inches; yield, 20 gallons a minute. About 95 feet of the well are in rock. The water can be used in boilers. For analysis see No. 12, table on pages 108–109.

OTHER WELLS NEAR NEW HAVEN.

The following data from New Haven and other towns of the lower valley are from Mr. Grant:

Additional wells at New Haven, Northford, and Montowese.

Serial No.	Town.	Owner.	Depth of well.	Depth to water.	Yield per minute.
			Feet.	*Feet.*	*Gallons.*
174	New Haven	G. W. Ives & Son	50	Flows.	
175		do	200		10
176		Seamless Rubber Co	160		10
177		H. H. Olds & Co	75	40	5
178		N. W. Capin	245	134	40
179	Northford	L. A. Smith	50	Flows.	
180	Montowese	J. F. Barnes & Co	36	32	7

All are 6 inches in diameter.

FAIR HAVEN.

No. 181. J. R. King.—Depth, 203 feet; diameter, 6 inches. When pumped at the rate of 40 gallons a minute the water level did not fall at all. The well is entirely in rock, and no water was found until after a depth of 100 feet was reached. The water gave no scale when used in boilers. Data are from R. A. Mather, of King & Mather, well drillers.

WELLS STOPPING AT SURFACE OF ROCK.

Another group of wells of an entirely different nature from those of the previous list comprises the deep wells of the drift, which were sunk to the top of the rock and stopped at that point. Data concerning a few of these are given on the following pages.

WELLS IN MASSACHUSETTS.

NORTHAMPTON.

No. 182. Belding Brothers' Silk Company.—This well is a close neighbor of the famous dry well, No. 1, of this paper. It passes at a considerable depth through a dense layer of some sort and then continues through gravel to the rock, which is here 150 feet below the surface. The yield of 20 gallons a minute does not materially affect the water level, which is about 20 feet below the surface of the ground. The water, which has not been analyzed, can be used in boilers, but is principally employed in dyeing. The diameter of the well is 12 inches.

SPRINGFIELD.

Nos. 14 and 15. Springfield Breweries Company.—These wells and the rock well belonging to the same company have been mentioned on an earlier page of this paper, under the numbers here given, and do not need further description. It is interesting, however, to note that the quality and quantity of the water changes as soon as the rock is entered.

No. 183. Phelps Publishing Company.—Depth, 78 feet; diameter, 2½ inches; yield, 10 gallons a minute. The water is too hard for boilers but is excellent as drinking water. This well, which stops at the rock, is pumped.

No. 184. Cooley's Hotel.—This is a driven well, 86 feet deep and 2½ inches in diameter, that yields over 20 gallons of water a minute. The water is soft and could probably be used for boilers. The well runs to the surface of the rock, at which point the water is obtained.

WELLS IN CONNECTICUT.

MERIDEN.

Nos. 185, 186, 187, 188, and 189. Bradley & Hubbard Manufacturing Company.—In 1890, five wells, each 8 inches in diameter, were driven to the rock by this company, reaching the following depths: No. 1, 203 feet; No. 2, 208 feet; No. 3, 256 feet; No. 4, 327 feet; No. 5, 281 feet. Only Nos. 1, 2, and 3 are used, as Nos. 4 and 5 did not produce water enough to pay for connecting. No estimate of the amount of water obtained from Nos. 1, 2, and 3, separately, can be given; but the three wells together furnish about 6,000 gallons an hour. None of the wells flow. The water is of fair quality, but is rather hard for use in boilers.

These five wells, all over 200 feet deep, run to the rock only. Besides their interest from the standpoint of the water supply, they give some very interesting suggestions concerning the depth of the unconsolidated deposits at this point, and they hint at the presence of a very deep depression in the underlying sedimentary rocks along the general line of the great fault which separates the Hanging Hills on the west from Lamentation Mountain on the east.

It should be noted that in this paper no account is given of those wells which lie wholly in the unconsolidated deposits of the area and which do not come into relation with the rock at all. There are many of these wells, and they seem to be especially in favor in the region lying between Springfield and Holyoke and along the Chicopee River. They present innumerable local problems of a diverse and often complicated nature, and any results which might be obtained from their study would be of relatively little economic importance.

TRIASSIC ROCKS OF THE CONNECTICUT VALLEY AS A SOURCE OF WATER SUPPLY.

By M. L. FULLER.[a]

INTRODUCTION.

In the foregoing paper of Mr. W. H. C. Pynchon detailed descriptions have been given of a large number of wells of the Triassic area of Massachusetts and Connecticut, together with a considerable amount of data relating to the quantity and quality of the water supplies which are obtained. Many facts bearing upon the occurrence of the waters have been presented and certain deductions that are of local application have been made.

The purpose of this paper is to supplement the foregoing by a general summary of the water conditions in their broader relations and to point out the significant features of the water supply of the region. The effort has been made to describe these features as concisely as possible rather than to present elaborate discussions.

In addition to the conclusions presented, a few notes on points of special interest to the driller have been appended.

UNDERGROUND WATER CONDITIONS IN THE AREA.

SOURCES OF WATER.

CONGLOMERATES.

Near the edge of the area, where the Triassic beds are in contact with the adjacent crystalline rocks, both on the eastern and western sides, there are somewhat marked bands of conglomerates which were deposited along the shores of the Triassic sea that occupied the basin.

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[a] The descriptive portions relating to wells are based on the field observations of Mr. W. H. C. Pynchon and are compiled from notes furnished by him. The present writer alone, however, is responsible for the interpretations of the various features and for the views expressed in regard to the nature, condition, and prospects of the water supplies in the Triassic area.

The pebbles of the conglomerate were derived from the adjacent crystalline rocks, and some of them are of large size. The matrix is of various degrees of fineness, ranging from coarse sand to clay. In Massachusetts the conglomerate on the west side of the Triassic area is known as the Sugarloaf arkose and on the east side in part as the Sugarloaf arkose and in part as the Mount Toby conglomerate, the latter occurring in a narrow belt between the Sugarloaf arkose and the crystalline border in the southern part of the State. The same bands extend into Connecticut and possibly continue throughout the entire southern part of the area, but they have not yet been differentiated in that region.

The conglomerates of the western border would at first sight seem to offer greater possibilities for the storage of artesian waters than any other rocks in the valley. They present their upturned edges to the waters that pour down from the western upland and are comparatively undisturbed by fracture and displacement, but because of their situation, outside of the immediate Connecticut Valley, where the principal towns are located, very few deep wells have been sunk in them, and it is therefore impossible to say whether actual results would agree with the assumed conditions. The few deep wells near the western border of which records are at hand do not reach the average depth of those of the central portion of the valley, and the fact that these few wells obtain only very moderate supplies is therefore inconclusive. Farther away from the border, as at Northampton, a well was sunk to a depth of 3,700 feet through rocks classed by Professor Emerson as Sugarloaf arkose without encountering water. Again, near Westfield, a well was sunk at Daniel Brothers' paper mill to a depth of 1,100 feet in the Sugarloaf arkose, likewise without success. In fact, so far as is known, nearly all wells that have reached great depths without procuring water have been sunk in the conglomerate or arkose.

On the eastern side of the valley the conditions are less favorable than on the west. The eastward sloping beds of the narrow belt of Mount Toby conglomerate that lies at its contact with the crystalline rocks along the eastern edge of the area abut against a system of faults that presumably constitutes an extended line of leakage, drawing water from the adjacent conglomerates.

SANDSTONES.

Distribution and character.—The sandstones, because of their great area and their water-holding capacity, are the principal source of water in the Triassic area. Except for the conglomerate belts along the eastern and western boundaries, the shale band near Connecticut

River at the center of the valley, and the trap ridges, the main portion of the area of Triassic rocks is underlain by sandstone. Many important towns are located in the sandstone area and a large number of wells obtain good supplies of water from this rock.

In character the sandstones vary from fine to coarse grained, and are usually some shade of red or brown in color, though buff and other varieties are known. They are often of very even texture and frequently occur in thick beds, so that from many standpoints they constitute an admirable building stone, for which purposes they are extensively quarried, especially at Longmeadow in Massachusetts and Portland, Cromwell, and Tolland in Connecticut. They are interspersed with beds of shale ranging in thickness from mere films up to beds many feet thick, which frequently serve as confining strata for the water-bearing beds.

A test of the brownstone from Portland, Conn.,[a] shows that this sandstone when previously dried and then immersed in water for three months will increase in weight from 150 to 154 pounds, showing an absorptive ratio of 4 to 150 or about one-fortieth of the weight of the block. This is equivalent to approximately 2 quarts of water to every cubic foot, and shows that, under favorable conditions, the rock has immense capacity as a reservoir.

Water supply.—The sandstones may be studied to good advantage in the quarries which lie within their borders at Longmeadow, Cromwell, or perhaps best of all in the great brownstone quarries at Portland, directly across the Connecticut River from Middletown, Conn. Here great pits have been opened in the sandstone to a depth of 200 feet, and the water-bearing character of the rocks may be studied. Although the sandstone when quarried contains a certain amount of "quarry water" when first removed from the pit, no water appears to percolate from the face of the stone, but water everywhere emerges from along the bedding planes, especially along the shaly partings, where, dripping down, it darkens the quarry walls over large surfaces.[b] The water flows chiefly down the slope of the dip and enters the rock in greatest amount during the spring months, at which period slight amounts may also enter from the opposite side. The beds slope from the Connecticut River toward the quarry, but the fluctuation in the amount of water entering the quarry with the season indicates its derivation directly from rainfall or melting snows. Throughout the busy season pumps keep the quarries sufficiently clear of water to permit work to be done.

A well showing features somewhat analogous to those seen at the quarries is located at the bottling establishment of M. M. Bacon, on Morris street, Hartford. It is an open well, 34 feet deep and about 2½ feet in diameter, about 14 feet of its depth being in shales. In one corner of the bottom of this well is a fissure large enough to allow the insertion of the fingers, from which the water flows in such abundance that it is impossible to keep the well dry enough for convenient cleaning. The draft on this well is a thousand gallons a day the year round, and in summer it will amount to half as much again. Though this well is in a city of 90,000 inhabitants, and is situated at the foot of a considerable drainage slope, yet the analysis which the city made of the water shows that it is very pure.

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[a] Stone, vol. 9, June, 1894, p. 20.

[b] Stone, vol. 9, pp. 42-43, 1898.

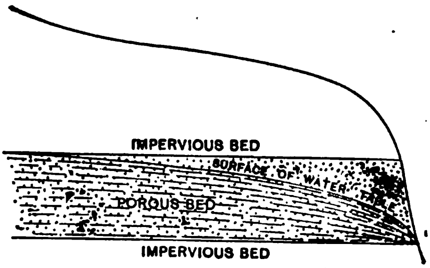

FIG. 20.—Depression of water surface at point of leakage in sandstone.

From the fact that the entrance of water into the quarries and in the well mentioned is from the bedding planes, it might appear that but little was contained in the body of the sandstones themselves. This appearance is, however, probably due to the artificial conditions of the exposures in the quarries. The sandstone, because of its open and porous texture, probably behaves much like a homogeneous mass of sand, from which the flow or leakage takes place along its contact with an underlying impervious bed or at the level of saturation. In such a mass the water table, as the upper surface of the water body which it contains is called, is depressed at the point of leakage, but rises gradually as the distance from the point of outflow increases (see fig. 20). Thus, in a sandstone bed it is but natural that the outflow should be only at its base, although perhaps a few feet back from the exposed face the whole bed may be saturated. This is true of practically all natural outcrops, even of the famous water-bearing Dakota and similar sandstones of the central West.

SHALES.

Character.—The largest body of shales in the Triassic area occurs near the central part of the valley, in the vicinity of Connecticut River. They are known in Massachusetts as the Chicopee shale, are grayish in color, and are interbedded with many sandstone layers. At the bottom they grade into the Longmeadow sandstone. In addition to the Chicopee shales, occasional thin shaly beds occur in the sandstones or conglomerates throughout the entire area.

Theoretically shales are not at all adapted to hold ground water, but in the shaly rocks under discussion there is considerable lime, and possibly, in the deeper portions, salt and gypsum, which by solution may readily give rise to channels for underground waters. The interbedded sandy layers and the bedding planes themselves would also furnish numerous channels for the passage of such waters.

Water supply.—That the shales bear considerable quantities of water is apparently shown by the success of the wells at Holyoke, Springfield, and other points in the belt of the Chicopee shales, although it is not impossible that the deeper wells enter the underlying Longmeadow sandstone and obtain a part of their supply from that formation. Among such wells may be mentioned Nos. 3, 4, 5, 7, 9, 10, 11, and 12, mentioned by Mr. Pynchon in the preceding paper. Wells 16 to 22 generally start in the Chicopee shales, although several of them may penetrate sandy beds, probably of the underlying Longmeadow sandstones.

Depth of wells.—Of the wells noted, two are between 100 and 200 feet, five between 200 and 300 feet, four between 300 and 400 feet, two between 400 and 500 feet, and three over 500 feet. This indicates that in general the wells must be fairly deep in order to obtain satisfactory supplies in the shale area.

Character of water.—Because of the presence of lime and other soluble mineral substances the waters from the shales are generally highly mineralized and can seldom be used in boilers.

TRAPS.

Catchment conditions.—Of the rocks of the Triassic area the traps present the most unfavorable conditions for water storage. This is because of the lack of porosity of the rock itself and of the absence of bedding planes along which the water might flow. Superficially they are extensively jointed and would absorb and hold much water if the open joints reached any considerable depth. It is probable, however, that below a relatively few feet from the surface the joints are in many places not sufficiently open to admit the passage of water. Moreover, the form of their outcrops is most unfavorable for the reception of the surface waters, as their exposed edges stand high above the surrounding plain, and usually rest upon an elevated pedestal of sediments. The western faces of the trap ridges, on which side they are most eroded, are precipitous cliffs, while their unbroken eastern slopes, plunging downward toward the plain at an angle of about 15°, send the waters collected from the rains in rushing brooks to the lowland. Indeed, throughout the valley the foot of the eastern slope of the Main sheet of trap is the favorite location for reservoirs. Hartford receives its water supply from a chain of such lakes that stretches for several miles along the eastern foot of the Talcott Range, while there are at least five reservoirs that use as their watershed the back slopes of the Hanging Hills. Farther down the valley Beseck Lake, Paug Pond, and Lake Saltonstall derive their supply from similar sources.

Wells in the trap.—Among the more interesting of the wells deriving their supply from the trap are those at Cedar Mountain, Wethersfield, just southwest of Hartford (No. 121, B. and C., of Mr. Pynchon). These wells are on the property of Dr. Gordon W. Russell, who sunk the wells largely as an experiment, and who has shown much interest in scientific matters. The mountain is a part of the ridge of the Main trap sheet, and has a maximum elevation of about 360 feet above the sea. Its western face is very steep, dropping 250 feet to the plain within a distance of two-fifths of a mile, and is actually precipitous near the summit. The eastern face slopes more gradually, dropping about 120 feet to the valley, occupied by shales, about three-fifths of a mile distant. It is in all respects a typical trap ridge.

Well A is an ordinary open well and was dug to supply the needs of the farm house. It was opened 9 or 10 feet to the rock, but the water became shallow in summer. It was then sunk 1 or 2 feet into the loose, greatly jointed surface trap, and has since given an abundance of water for domestic uses. The supply, however, fluctuates regularly with the wetness or dryness of the season. From the well mouth the mountain side with its drift covering rises steadily for two-fifths of a mile to the west till it reaches the crest, which is about 100 feet above the well. The supply is clearly the surface water contained in the soil and in the heavily jointed upper surface of the trap, the source also of a little stream which lies a little farther up the ridge.

Well B is located about 200 feet south of well A. It passes through 9 feet of soil and then through about 290 feet of trap rock, at which point the string of drilling tools wedged fast, possibly along a joint plane. The well is 6 inches in diameter. On illuminating it brightly for a considerable depth, by light reflected from a mirror, it appeared that no water came into it except from the shattered upper surface of the trap sheet, as in well A. The drill had not entered the underlying sediments when the well was visited in 1902, notwithstanding the fact that the bottom of the well was much below the level of the western plain.

Well C is located about three-fourths of a mile farther south and a little farther east than the other two wells. It has a depth of 103 feet. It was thought from the residue brought up by the sand bucket that the well entered the sedimentary beds below, but in view of the record of well B and the thickness of the Main sheet, this is extremely doubtful. Water was struck at a depth of 38 feet from the surface, in a joint, the yield being 32 gallons an hour. At the present depth the well is capable of giving 90 gallons an hour, the water probably coming through joints from a level below the well bottom, and rising to within 25 feet of the surface. During the drilling light was reflected down the bore and water was seen coming in through the trap, and, in the opinion of the driller, Mr. H. B. King, of Hartford, from the down-hill side. However this may be, we have here a well near the summit of the mountain whose bottom is above the level of the lowlands on either side, with water coming in through the trap and rising to a point about 175 feet above the plain three-fourths of a mile to the west and about 70 feet above the valley one-fourth of a mile to the east. The top of the well is about 280 feet above sea level.

GEOLOGY.

STRUCTURE.

Attitude of beds.—The dip of the beds of the Triassic area averages about 15°, or nearly 2,000 feet to the mile. The catchment area of an individual bed having a dip as steep as this is very narrow as compared with that of a more gently inclined bed. Thus, in figs. 21 and 22 beds having the same thickness and dipping 15° and 5°, respectively, are represented as outcropping on a level surface. It will be seen that the catchment area is smaller at the outcrop of the more steeply dipping bed.

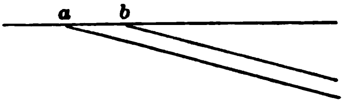

FIG. 21.—Outcrop of bed dipping 15°.

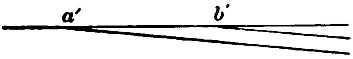

FIG. 22.—Outcrop of bed dipping 5°.

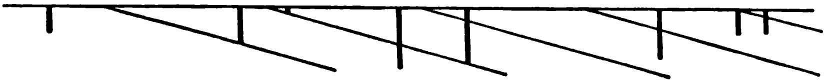

FIG. 23.—Conditions and beds encountered by wells.

Because of the steep dips and the rapidity with which the beds are carried to great depths a single water horizon is available only within very narrow limits. In fact, in going from west to east practically every well, unless the wells are very close to one another or penetrate to a great depth, draws from a separate horizon (see fig. 23). This is the explanation of the great variability in the quantity and quality of the water drawn from wells in the Triassic area.

Along the western rim of the area the Triassic rocks lie about 200 feet higher than in the lowlands of the Connecticut Valley. If the beds were continuous and were near enough to the surface in the center of the valley to be reached by the drill, artesian flows would probably be uniformly obtained. In reality, however, the beds are not continuous, but are broken by faults along which the waters can escape, and, moreover, they lie at such great depths that they can not be economically reached. The bed from which a 500-foot well draws its supply will outcrop within about a quarter of a mile of the well.

Direction of movement of water.—Although extensive artesian fields are unknown, and are in fact not to be expected, isolated flowing wells sometimes occur. A number have been mentioned in the description of the wells by Mr. Pynchon, pages 76 to 96 of this report. In most instances the water moves down the dip, but in a few wells the reverse seems to be true.

A well of the Connecticut Valley Brewing Company, at Thompsonville (No. 26 of Mr. Pynchon's list), is located on a neck of land that projects westward into the Connecticut River, to which a steeply sloping bank is presented. The water is obtained from the rock about 30 feet from the surface, the water-bearing bed rising toward the river and outcropping in the steep bank mentioned. The well yields 8 gallons a minute, a quantity many times greater than any amount that could be absorbed from the steep and narrow catchment area. The water can not possibly come from the river, as its level is about 25 feet higher than the level of the water in the river, but must come up the dip from the east. As the beds never bend upward and appear at the surface, but maintain their uniform dip to the east, the water can not be derived from any outcrop lying farther east. Joints or faults apparently present the only means by which the water can be supplied (fig. 24).

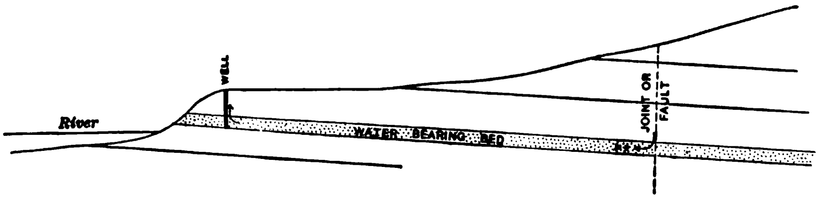

FIG. 24.—Underground conditions in Thompsonville well.

A well drilled a few years ago on Talcott Mountain, near the site of the "Old Talcott tower," of local fame, was situated on the crest of the ridge at a point a little over 900 feet above the sea. The face of the mountain falls away steeply to the west 700 feet in two-fifths of a mile. At a depth of 200 feet the drill passed through the trap into the underlying sediments, and at this point the only water was found. Presumably it was in small quantity, as the drilling was carried 700 feet farther, but without results. As the crest of the mountain is 700 feet above the western plain, and as the trap was left at a point only 200 feet down, the contact upon the face of the mountain must be over 500 feet above the plain. This would bring the outcrop of the contact only a little over one-tenth of a mile west of the well and on a precipitous portion of the mountain face. It is thought probable by Mr. Pynchon, who reported the well, that the water found, however small the quantity, came up rather than down the slope of the beds. Well No. 52, Ropkins & Co., Hartford, is probably of the same general type, as when allowed to stand the water rises in the well far above the water levels of the Park and Connecticut rivers, which are close by.

JOINTS.

Occurrence.—Joints are especially numerous throughout the Triassic area, the traps, conglomerates, sandstones, and shales all showing many of them. In the traps, as has been pointed out, the rock is sometimes superficially broken up into a mass of small blocks, among which the water freely circulates.

Joints are also well developed in the shales. This may be seen readily in the city quarry at Hartford, previously mentioned, where the shales forming the floor of the quarry are traversed for long distances by joint cracks that divide the rock into the diamond-shaped blocks already described. In this quarry a number of feet of the indurated shale have been removed, leaving an escarpment of sedimentary rocks, averaging fully 10 feet high, immediately below the trap. The joint planes bounding this face cut through many layers, some of them probably traversing the whole vertical distance. An examination of any fairly extensive outcrop of shale within the lowland will show that jointing is developed everywhere to the same extent.

The sandstone beds are likewise commonly jointed when exposed at the surface, but to what depth pronounced jointing extends is unknown, although the jamming of drills in certain wells may indicate that fissures extend to considerable depth in the sandstone. Thus in the well of the Hubert Fischer Brewing Company, of Hartford (No. 44), the drill, after penetrating "blue stone," entered what seems to have been a conglomerate, soon after which it became jammed, presumably by encountering a joint plane. On its liberation water began to flow. Again, at Hotel Russwin, New Britain, a well penetrated 140 feet of sandstone, etc., without finding enough water to keep the drill wet, but at that depth the drill became jammed in what appeared to be a crack about 2 inches wide. As in the preceding well, an ingress of water followed the loosening of the drill. The apparent breadth of the crack may in reality be due rather to the presence of soft, decomposed rock along the joint plane than to an actual opening of the size indicated.

Effect.—Several different, and in two instances entirely opposite, effects are produced by the joints of the Triassic rocks. Superficially they greatly favor absorption of water, and it is probable that the shallow supplies, especially those reached by wells 50 feet or less in depth, are greatly increased by their presence. Doubtless the most common result of the jointing, however, is to break the continuity of the shale or other confining beds associated with the water horizons, and thus to permit sufficient leakage in most instances to destroy the prospects of artesian flows. In a few cases, on the other hand, the supplies of deep beds seem to be derived from joints rather than from outcrops, as was notably the case of the Thompsonville well (No. 26), described on page 82, where the water, as indicated in fig. 24, appears to have passed down the joint and up the dip of the sandstone bed nearly to its outcrop, giving, in fact, true artesian conditions.

FAULTING.

Occurrence.—Although jointing disturbs the continuity of the beds almost universally, it does not do this so profoundly as do the manifold faults that cross the area in several directions, especially from north to south. Reference to the map accompanying Professor Davis's paper[a] will show that important faults exist in great numbers, but numerous as they are, as shown on the map, a many times greater number of faults, too small to be recorded, yet of sufficient size to entirely destroy the continuity of the beds in their immediate vicinity, occur in the area. When the extensive brecciation and local bending of the strata that must take place along the greater faults—faults having a length to be reckoned in miles and an upthrow to be calculated in hundreds and in some cases thousands of feet—are taken into consideration, it may be readily seen how thoroughly and extensively the continuity of the strata is destroyed.

Effect.—The effect of faults is much the same as that of joints, but, because of the relatively greater influence of faults at considerable depths, it is even more important. As the jointed upper portions of traps and other rocks are reservoirs of water, so the fault breccia, or the crushed material along faults, forms an important source of water. Among successful wells located almost upon the breccia of faults may be mentioned Nos. 44, 45, 46, 47, 48, 49, and 55 of Mr. Pynchon, lying near the fault cutting off the north end of Cedar Mountain, near Hartford. Wells Nos. 124, 125, 126, and 127 at Berlin and No. 130 at New Britain are almost on fault lines, while the town of Meriden with its wells is bounded on the northwest and the southeast by the two greatest faults in the whole lowland, the distance between the faults at this point being only 1¾ miles.

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[a] Davis, W. M., The Triassic formation of Connecticut: Eighteenth Ann. Rept. U. S. Geol. Survey, Pl. XIX.

COMPOSITION OF TRIASSIC WATERS.

Many facts bearing on the composition of the Triassic waters are given by Mr. Pynchon in the preceding paper, especially those bearing on the practical question of their adaptability for boiler use. The analyses of the waters of most of the wells described by Mr. Pynchon are not now available, but the results of the chemical examinations of a number of similar waters from Triassic rocks are given in the following table.

Analyses of waters from Triassic rocks of Connecticut.

[Compiled from H. E. Gregory's report, Water-Supply and Irrigation Paper No. 102, pp. 127-159.]

Number.	County.	Town.	Owner.	Source of water.	Depth of well.	Character of material.	Iron.	Calcium.	Magnesium.	Iron oxide.	Iron and aluminum oxides.	Lime.	Lithia.	Iron carbonate.	Calcium carbonate.	Magnesium carbonate.	Sodium carbonate.	Calcium sulphate.	Magnesium sulphate.	Calcium nitrate.
1	Hartford.	Bloomfield	H. C. Douglas et al	Well	101	Rock	15						1		54			1,108	525	
2		Crescent Beach	Atwood Collins	do	94	do	Tr.													
3		Hartford	Capewell Horse Nail Co	do	250	Red rock				1					158			272	155	158
4		do	City	do	250	Blue slate														
5		Simsbury	W. L. Cushing	do	218	Sandstone														
6		South Manchester	Cheney Bros	do	457	Red sandstone					1					41	25	1,508		
7		Windsor	H. J. Fisk	do	135							241							241	
8		Windsor Locks	Windsor Locks Water Co	Spring		Trap														
9	Middlesex.	Middletown	L. D. Brown & Co	Well	292	Brown sandstone.														
10		do	W. E. Wilcox	Spring										1	24	22		2		
11	New Haven.	Highwood	Marcus Wooding	do		Sandstone														
12		New Haven	New England Dairy Co	Well	157															
13		do	F. B. Shuster Co	do	72			74	11											
14		do	G. D. Watrous	do	75	Rock														
15		do	W. S. Swayne	Spring		do														
16		North Haven	B. F. Judd	do		Trap														

Analyses of waters from Triassic rocks of Connecticut—Continued.

[Compiled from H. E. Gregory's report, Water-Supply and Irrigation Paper No. 102, pp. 127-159.]

Number.	County.	Town.	Owner.	Source of water.	Depth of well.	Character of material.	Sodium chloride.	Potassium chloride.	Chlorine.	Carbon dioxide.	Sulphuric acid.	Phosphoric acid.	Organic and volatile matter.	Total mineral matter.	Hardness.	Silica.	Sodium sulphate.	Potassium sulphate.	Analyst.
1	Hartford.	Bloomfield	H. C. Douglas et al	Well	101	Rock	337					60	410	2,523		20			Unknown.
2		Crescent Beach	Atwood Collins	do	94	do			22					132	26				Do.
3		Hartford	Capewell Horse Nail Co.	do	250	Red rock	37							940		18	222	6	Do.
4		do	City	do	250	Blue slate			13		358			628	240				H. E. Smith.
5		Simsbury	W. L. Cushing	do	218	Sandstone			2					69	28				Do.
6		South Manchester	Cheney Bros.	do	457	Red sandstone	4							1,636		21	32	8	Unknown.
7		Windsor	H. J. Fisk	do	135				10										Do.
8		Windsor Locks	Windsor Locks Water Co.	Spring		Trap							20	56	29				S. P. Wheeler.
9	Middlesex.	Middletown	L. D. Brown & Co.	Well	292	Brown sandstone.			10					110	52				Unknown.
10		do	W. E. Wilcox	Spring			2							61		10			Do.
11	New Haven.	Highwood	Marcus Wooding	do		Sandstone			3					60	23				H. E. Smith.
12		New Haven	New England Dairy Co	Well	157				10					110	52				Do.
13		do	F. B. Shuster Co	do	72				44		26			404					Unknown.
14		do	G. D. Watrous	do	75	Rock			3					48	35				H. E. Smith.
15		do	W. S. Swayne	Spring		do			3					93	23				Do.
16		North Haven	B. F. Judd	do		Trap			2					32	6				Do.

One of the striking features of these wells and springs is the great variability of the waters. Those of the traps are comparatively low in mineral matter, carrying in one case, at North Haven (No. 16), as low as 32 parts per million of dissolved solids. From 400 to 2 500 parts per million are common in waters from the sandstones and shales (Nos. 1, 3, 6, and 13). Such amounts make the water unfit for boiler use, even where the mineral matter is mainly present as carbonate (lime). The analyses show that not only is lime present in large amounts, but that there are considerable quantities of the much more objectionable sulphates. The three springs mentioned are very low in mineral, the water in two of them, if not in all three, coming from the trap.

SUMMARY OF WATER CONDITIONS.

ESSENTIALS OF ARTESIAN FLOW.

In 1885 Professor Chamberlin published a paper[a] that explained the principles of artesian flow and called attention to many of the special conditions that tend to determine the success or failure of artesian wells. The conditions favorable to true artesian flow are as follows:[b]

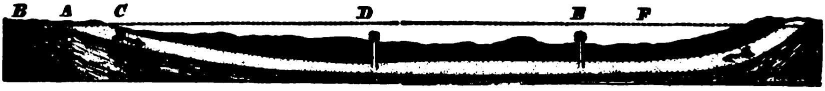

FIG. 25.—Ideal section showing the requisite conditions of artesian wells.

1. A pervious stratum to permit the entrance and the passage of water.
2. A water-tight bed below to prevent the escape of water downward.
3. A like impervious bed above to prevent the escape upward, for the water, being under pressure from the fountain head, would otherwise find relief in that direction.
4. An inclination of these beds, so that the edge at which the waters enter will be higher than the surface at the well.
5. A suitable exposure of the edge of the porous stratum, so that it may take in a sufficient supply of water.
6. An adequate rainfall to furnish this supply.
7. An absence of any escape for the water at a lower level than the surface at the well.

The requisites as outlined above apply only to sedimentary rocks, but the principle on which artesian flow depends is equally applicable to other rocks, the essential feature being simply that the water be confined and that the outlet through the well be considerably lower

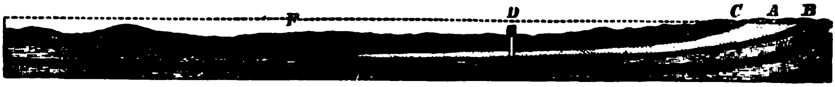

FIG. 26.—Section illustrating thinning out of porous water-bearing bed.

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[a] Chamberlin, T. C., Requisite and qualifying conditions of artesian wells: Fifth Ann. Rep. U. S. Geol. Survey, pp. 125-173.

[b] Ibid., p. 13.

than the catchment area at which the water enters. A bedding, joint, or fault plane or other fissure in the insoluble rocks, or a solution passage in limestones sometimes affords favorable conditions for artesian flow, but such features are usually of limited and local development and are therefore a far less common source of water than the widely distributed beds of sedimentary origin.

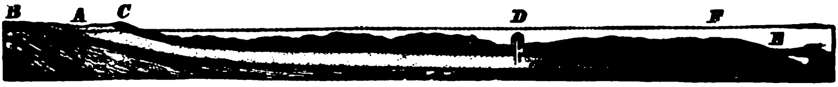

FIG. 27.—Section showing transition from porous to impervious bed.

CONDITIONS IN THE TRIASSIC AREA FAVORABLE TO FLOWS.

The conditions in the area that are favorable to artesian flow may be summarized as follows:

1. There are many porous beds which water may readily enter and through which it may find ready passage.
2. Water-tight beds, serving to confine the waters, frequently occur both above and below the water-bearing sandstones.
3. The beds are so inclined that the edges at which the waters enter are often higher than mouths of the wells.
4. The edges of the beds are so exposed that water can be readily absorbed.
5. The rainfall is adequate for large supplies.
6. In some places joints and faults appear to conduct water downward to the porous sandstones, which thus obtain their supplies.

CONDITIONS IN THE TRIASSIC AREA UNFAVORABLE TO FLOWS.

The conditions unfavorable for flowing wells in the area may be stated as follows:

1. The beds are so highly inclined that the areas exposed at the surface for the catchment of waters are small.
2. The inclination of the beds is such that, except in very deep borings, the outcrop is near the well and is at only a slightly greater altitude.
3. The rocks are so cut by joints and faults that ready escape is frequently afforded for the rock waters, thus neutralizing the several favorable conditions noted.

CONCLUSIONS.

The conclusions reached as to the underground water conditions on the area may be summarized as follows:

1. Rock waters are generally present in almost all of the rocks of the Triassic area.
2. In the sedimentary beds the rock waters appear to be most abundant in the sandstones, less abundant in the shales, and least abundant in the arkose and conglomerates occurring around the rim of the area. Little water is ordinarily afforded by the traps.
3. Many of the conditions favorable to artesian flows are locally present, and flowing wells will occasionally be found.

4. Because of the frequent interruption of the continuity of the water-bearing beds by joints and faults, artesian flows will be relatively rare and confined to small areas.

5. The dips are so steep that the water-bearing beds usually outcrop within a short distance from the wells and at only a slightly greater elevation; hence the head will probably never be great, and for ordinary purposes pumping will always be necessary.

6. Because of the steepness of the dip different wells, except where close together, will rarely pass through the same series of beds, but will generally show wide differences in the materials encountered and the quantity and quality of water procured.

7. Supplies sufficient for many ordinary manufacturing processes will be obtained from wells in the Triassic sandstones, but such enormous supplies, amounting to several thousand gallons a minute, as are obtained from some of the wells in the loose, porous beds of the Coastal Plain will not be found. The amounts given in the description of the wells in the paper by Mr. Pynchon indicate the character and limitations of the supplies that may reasonably be expected.

8. The waters will generally be highly mineralized, and it will usually be impossible to use them in boilers. The waters of the traps will on the whole probably be found freest from mineral matter and those of the shales will show the highest mineral content. The contrast between these waters and the pure soft waters of the crystalline rocks of the surrounding area is very striking.

9. The water will commonly be free from pollution by sewage or other extraneous matter. High chlorine, usually regarded as an indication of sewage contamination, may result from the solution of matter from the rocks, especially from the shales. In cities, however, where the rocks outcrop, as they frequently do, within the corporate limits, the water should be used for drinking only after it has been thoroughly tested, as surface waters may in some instances pass readily into the rocks. The wells should be carefully cased and packed to prevent water from passing downward along the pipe.

10. The source of the water supply is mainly the rainfall in adjacent regions. When the rocks outcrop at the surface, the water may be absorbed directly, but probably the greater amount is absorbed from the ground water in the glacial drift which overlies the rocks over large areas.

11. The waters pass through the rocks in part by general seepage and in part by following bedding, joint, or fault planes. The former method is more common in the porous sandstones, the latter in the shales and traps.

NOTES ON WELL DRILLING.

TESTING OF WELLS.

Attention has been called by Mr. Pynchon to the failure of a number of very deep wells, notably the 3,700-foot well at Northampton and the 1,100-foot well near Westfield. Although such wells have failed to obtain supplies, practically all of them encounter water in small amounts, which is generally cased off as the well proceeds. No such well should ever be abandoned without a thorough test of every water horizon, however small. The casing, if possible, should be raised above the level of the water-bearing bed, a pump inserted, and the supply measured. When it is impossible to remove the casing, it can be destroyed at the water horizon by a shot of nitroglycerin, which will also at the same time tend to loosen up the surrounding rock and increase the flow. Supplies have frequently been developed at horizons which were not at first thought worthy of testing and which were originally drilled through without stopping and cased off.

Anything that tends to increase the chances of success of wells is to the ultimate advantage of the driller. A complete failure, such as the well at Northampton, while it may cause the owner to sink the particular well to a great depth and thus give temporary employment to the driller, will tend to deter others in the vicinity from drilling, and will in the end result in a decrease in the total amount of drilling done. If such failures can be partially or wholly prevented, the drilling business will be proportionately benefited. The drillers themselves should use all possible effort to make every well successful, for each successful well is likely to lead, sooner or later, to the sinking of others.

KEEPING OF RECORDS.

One of the chief factors in the development of a well, as has been pointed out, is the thorough testing of each water horizon. Detailed notes should therefore be made of the character of material penetrated by the drill and the amount and quality of the water from each horizon, wherever encountered, and the depth of each horizon should be determined by actual measurement. The memory can not be relied upon and should not be trusted to recall the depths at which water may be struck, for although the facts are firmly impressed upon one at the time, they are gradually lost sight of during later development, so that if, at the completion of the well, it becomes necessary to test any particular horizon only a general guess as to its depth and as to the character of the material at that point can, in many instances, be made. Many wells have resulted in failure because the water horizons passed through in the earlier stages of the drilling and cased off could not be relocated.

PROPER DEPTH OF WELLS.

Nothing can be farther from the truth than the popular fallacy that water can always be found in great quantities if the well is only drilled deep enough. On the contrary, it is almost universally the case in this region that wells of moderate depth yield the most abundant supplies. The reason for this lies in the fact that all of the rock waters originally come from the surface and decrease in amount as the depth becomes greater. In the upper rocks joints and other crevices are both more numerous and more open than in the deeply buried rocks, and the absorptive and water-holding capacities of the upper rocks are correspondingly greater. Being subject to weathering and solution by circulating waters, the rocks near the surface are also much more porous than those lying deeper.

The depths to which wells should be sunk will differ greatly in different areas. What would be a shallow well in many regions would be a deep well in the Triassic region. In general, wells in this area that are under 300 feet in depth give the best supplies, while very few find their main supplies below 500 feet. There would probably be few exceptions to the principle that two 250-foot wells will give more water than one 500-foot well. This is even more true of the deeper wells. For the cost of the 3,700-foot well at Northampton fifteen or more 200-foot wells could have been sunk, and a good supply of water would almost certainly have been obtained.

It can therefore be said that success in procuring large supplies in the Triassic area is generally to be obtained rather by drilling a number of shallow wells than a single deep one.

SPRING SYSTEM OF THE DECATURVILLE DOME, CAMDEN COUNTY, MISSOURI.

By E. M. SHEPARD.

DESCRIPTION OF DOME.

The magnitude of the springs of the Ozarks, especially of the group gushing to the surface in Camden and adjacent counties in Missouri, has long been noticed, and the remarkable rounded mass or boss of coarsely crystalline granite, known as pegmatite, in the neighborhood of Decaturville, in southern Camden County (see fig. 28), has also been for many years an object of interest. During a trip made

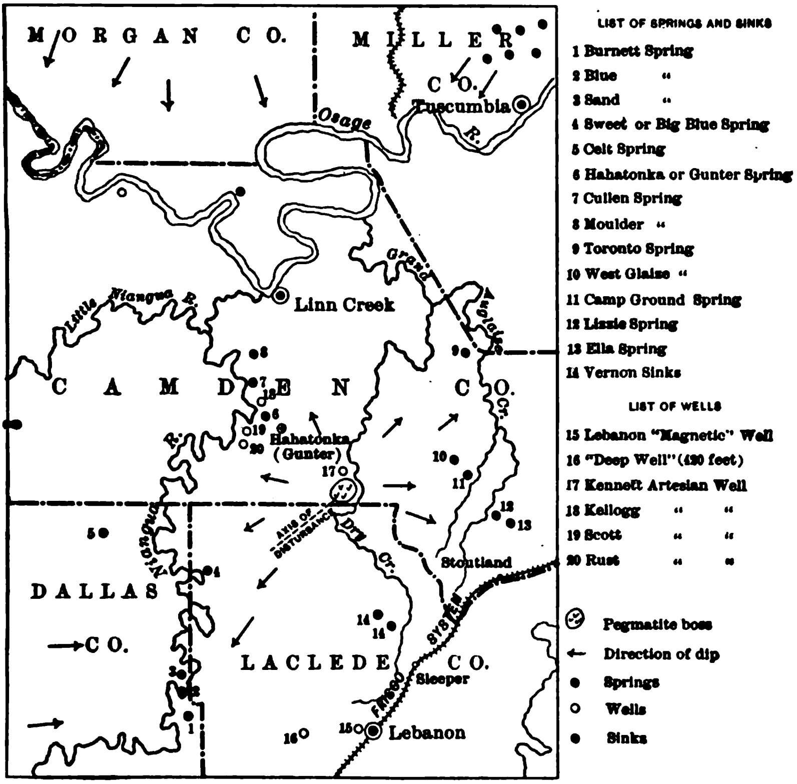

FIG. 28.—Sketch map of region of Decaturville dome, Missouri.

through this region early in the summer of 1903 to investigate the underground waters of the State, the idea occurred to the writer that some relation existed between the granite mass and the system of great springs and sinks that surrounds it for a distance of from 8 to 12 miles, or possibly farther. Subsequent study has confirmed this opinion and has revealed a unique condition of underground drainage.

In 1869 some miners who were prospecting for lead laid bare, close to the surface, a small area of granite or pegmatite, frequently called graphic granite because of a peculiar crystalline structure resembling the letters of an ancient alphabet. This is situated at the crest of a low, dome-shaped hill covering about 6 acres and elevated about 40 feet above the level of the land in the immediate neighborhood. The miners were led to prospect here by finding some small rounded bowlders of quartzite and graphic granite at the surface. This small exposure of granite is located near the town of Decaturville, in the southeast corner of the SW. ¼ of sec. 32, T. 37 N., R. 16 W., near the line between Camden and Laclede counties, on land now owned by Mr. Samuel Wheeler. The excavation was only 20 feet long, 10 feet wide, and probably 30 feet deep, though it is now partially filled up. When first opened the material immediately beneath the soil consisted of an incoherent layer, several inches in thickness, of kaolinized feldspar and mica, which gradually merged into a true pegmatite, made up mainly of the variety of feldspar known as microcline, with some albite and oligoclase feldspars and numberless small masses of quartz. On the south side an irregular, sheet-like mass of fine-scaled to somewhat granular, ferruginous, micaceous schist (evidently metamorphosed gouge) was found. The mica was all common muscovite. Scattered over the surface of the hill were lenticular or irregular masses of polished, compact quartzite, somewhat resembling glacial bowlders of the same material. If, as the writer believes, these are the metamorphosed remnants of a fractured intercalated layer or bed

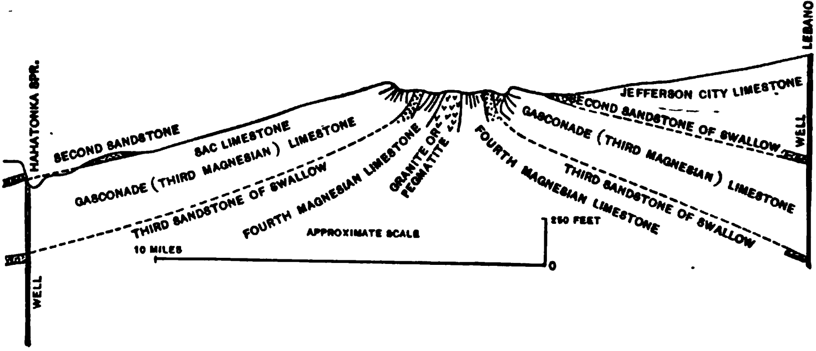
HAHATONKA SPR.
WELL
SECOND SANDSTONE
SAC LIMESTONE
GASCONADE (THIRD MAGNESIAN) LIMESTONE
THIRD SANDSTONE OF SWALLOW
FOURTH MAGNESIAN LIMESTONE
GRANITE OR PEGMATITE
APPROXIMATE SCALE
10 MILES
250 FEET
0
FOURTH MAGNESIAN LIMESTONE
THIRD SANDSTONE OF SWALLOW
GASCONADE (THIRD MAGNESIAN) LIMESTONE
SECOND SANDSTONE OF SWALLOW
JEFFERSON CITY LIMESTONE
WELL
LEBANON

FIG. 29.—Ideal cross section from Hahatonka Spring to Lebanon.

of sandstone in the original dolomite, they form, with the mica-schist, the only evidence of metamorphism found. Most of these bowlders have been carried away, many of them having been thrown into the old pit and many used in the construction of an adjacent stone wall.

The dike or boss is surrounded by siliceous magnesian limestone, corresponding to Swallow's Fourth Magnesian limestone. The greatly tilted and in many places nearly vertical ledges indicate great disturbance. The limestone here, while not metamorphosed, is decidedly altered, being highly silicified as well as pitted and honeycomed to a remarkable degree. A quarter of a mile away to the north, east, south, and west, these ledges outcrop in a way that reminds one strongly of coral reefs exposed at low tide. Great parallel ridges, tilted at every angle and some nearly vertical, stand up in irregular segments about the granite hill. To the southwest for over 2 miles, along the narrow valley of Spencer Branch, the disturbance is very great. The axis of this lateral disturbance extends S. 52° W., and the rocks on both sides of the valley dip strongly toward this axis.

About 500 feet southwest of the hill three small shafts were sunk several years ago. The surface was covered with soil mixed with an earthy hydrated iron sesquioxide. In the first shaft, 27 feet deep, a mass of very soft earthy galena, 2 feet wide and 3 feet thick, was found. This seemed to extend about 8 feet to the northeast. The second shaft was 12 feet deep, contents unknown. The third was 53 feet deep, and Mr. Wheeler, the owner of the land, states that granite was found at the bottom. A very impure earthy galena, mixed with zinc silicate and iron pyrites, was found in three V-shaped pockets or flat openings, one above the other, which pitched strongly to the west, toward the prolonged axis of disturbance. About a quarter of a mile to the southwest, along this axis, Mr. Wheeler sunk a fourth shaft, depth unknown, at which, on the dump, there were exposed masses of a highly silicified rock mixed with a curious iron breccia and conglomerate, with scattered masses of earthy limonite.

Surrounding the pegmatite outcrop, except at the southwest, is an irregularly broken circle of low hills that stand about 60 feet above the general level of the basin, making the whole area resemble somewhat the contour of an old crater. The Third sandstone of Swallow outcrops in vertical ledges that form an irregular circle about three-fourths of a mile in diameter around the pegmatite outcrop. This sandstone was first observed just south of the hotel at Decaturville, where a large exposure may be seen. The vertical beds here are about 25 feet thick. The false bedding and the more siliceous, irregular layers, standing out as ridges, are characteristic of this formation. The sandstone is somewhat hardened at the surface. Farther west, other outcrops of vertical sandstone ledges are found in juxtaposition with vertical ledges of the Fourth Magnesian limestone on the inner side, and vertical ledges of Gasconade limestone, or the Third Magnesian limestone of Swallow, on the outer side. Two of these outcrops are particularly striking, one near the center of the south line of section 29 and the other near the point where the road crosses the dry branch of Banks Creek, which heads to the southwest, close to the granite outcrop near the southwest corner of the same section. Farther west and south another striking vertical outcrop of this sandstone forms a "backbone." An interesting feature of these sandstone outcrops is the fact that, on either side of them, the dips of the Gasconade limestone and Fourth Magnesian limestone range from vertical to a strong inclination inward toward the sandstone, a condition very difficult to explain, but which may possibly indicate a second and more local uplift. A few hundred feet southwest of the pegmatite outcrop several shafts already described have been opened and small amounts of earth, impure galena, and zinc ore have been found.

Within a radius of a mile or two of this pegmatite outcrop Mr. W. S. Rush, of St. Joseph, has sunk a number of diamond-drill holes to a depth of several hundred feet, and in no case did he strike the pegmatite. These holes were all sunk in search of mineral. A third of a mile north of Decaturville, in the southwest quarter of section 28, is a small outcrop of Hannibal shales and Sac limestones (Devonian). The limestone contains cavities filled with calcite and is somewhat altered structurally, though its lithological characters serve to identify it without much doubt. The shales, presumably the Hannibal, are greatly altered and are of a bright-yellow color and of a soft, clay-like texture. The blue color which everywhere else characterizes these shales has evidently been destroyed by the heat attending the uplift. In the valley a few hundred feet to the south is a tilted outcrop of greatly altered dolomitic limestone, which is doubtfully referred to the Jefferson City limestone (Second Magnesian of Swallow), or possibly to the First Magnesian of Swallow.[a] As far as the writer knows, these are the highest rocks exposed anywhere in this county or the adjoining counties to the south. It is significant to note that these upper beds retain to a considerable degree their dolomitic character. In other words, these remnants of superincumbent beds have not undergone replacement by silicification, as has been the case in lower beds, which will be described later.

There is evidence of two distinct periods of uplift, both of which must be post-Devonian. From data obtained in other parts of the Southwest it is presumed that the first uplift was post-Carboniferous, when the great dome of the Ozarks was first elevated. From the obscure evidence furnished by the lateral anticlines that merge into the main axis of the Ozarks at divergent angles—anticlines which, the writer believes, were formed in post-Tertiary time, when the lead and zinc ores of the Southwest were probably deposited—he would date the second uplift at this point in geological time.

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[a] The above locality was recently visited by Dr. E. O. Ulrich and the writer. From fossils there obtained Doctor Ulrich determined that these beds probably belong to the Richmond formation of the Ordovician.

In passing in any direction outward from the center of maximum disturbance one may readily note that the rocks tilt less and less strongly away from the pegmatite hill (see figs. 28, 29).[a] This is strikingly shown along the bluffs of Banks and Spencer creeks.

SPRINGS.

From what has been said it is evident that the area of upturned strata surrounding the pegmatite hill—an area 3 or 4 miles in diameter—forms a splendid catchment basin, which contributes to the supply of the great fountains that lie in the surrounding region. Studies of the counties adjoining Camden, particularly on the west, northwest, north, and northeast, indicate a general dip of the strata toward the dome. The water from the catchment basin around the dome therefore meets in a trough, at considerable depth, the circulating water derived from the outside area, and the body of water thus gathered from the drainage on both sides, being under pressure, is forced up to the surface. Where erosion has cut sufficiently deep into the valleys of the Big Niangua, Osage, and Auglaize rivers, which surround the pegmatite hill on the west, north, and east, great springs issue at a distance of from 8 to 15 miles from the granite outcrop. Along the course of Spencer and Banks creeks, which drain this same territory to the northwest, numerous small springs issue, the valleys not being cut deep enough to tap the larger supplies below.

Bennett or Bryce Spring.—The springs of the Decaturville system will be taken up in order from the southwest. The first and largest of the group is the Bennett or Bryce Spring, situated on the west side of Dallas County near the Laclede County line, in sec. 1, T. 34, R. 18, at an altitude[b] of 940 feet, 150 feet below the pegmatite hill and about 15 miles southwest of it. It issues from the lower beds of the Gasconade limestone, the Third Magnesian of Swallow. The temperature of the spring was 57.5° F. when the air temperature was 86° F. Swallow, who visited it in 1853, gives the temperature of the water at 58° F. and that of the air at 60° F. The calculated flow was 172,388,800 gallons a day, but Swallow's figures give only 81,084,810 gallons a day, a remarkable variation in volume. This wonderful spring lies in a narrow valley about 600 feet wide. It boils up with great force from a vertical, cave-like opening into a large oval basin (see fig. 30). The spring was sounded to a depth of 22 feet. Mr. Trueman Atchley, who has lived near it for many years, states that he has seen it with one-tenth less water than normal and once 3 feet higher than normal, a condition which would give it twice the flow above calculated. The channel just below the outlet of the spring has become somewhat filled up with gravel, so that the water surface has been raised above the height of the place of outlet. Mr. Atchley states that before the outlet was thus choked he has seen the spring so low that he could walk around the upper portion of the cave-like opening. He states, also, that this opening descends 20 feet vertically and then slants southwestward to an unknown depth at an angle of 40° to 50°. When visited by the writer the water of this spring boiled up strongly over an area about 20 feet in diameter and to a height of 2 or 3 inches above the general level of the pool. The spring forms a river that is 100 feet wide and averages 1½ feet in depth, with a rapid current.

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[a] Except at a point 10 miles northeast of Decaturville, in the SW. ¼ of T. 38, R. 14, where the rocks are greatly disturbed and tilted along a northeast and southwest axis. Whether this is a continuation of the Decaturville axis or not can not be determined at this time.

[b] All the altitudes given in this paper, except that of Lebanon, were determined by a series of barometric observations and are believed to be approximately correct.

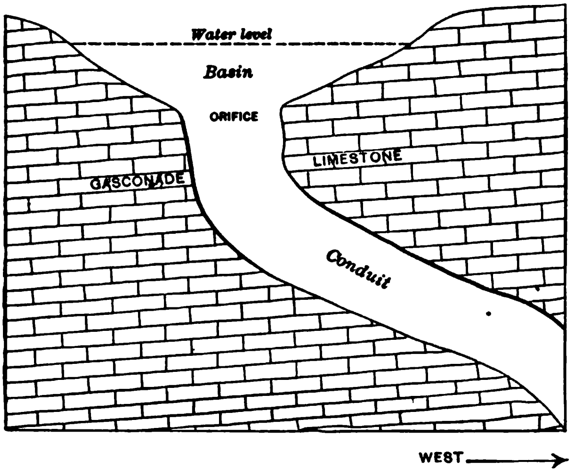

FIG. 30.—Diagrammatic cross section of Bennett Spring.

Farther west, in Dallas County, the rocks have a general eastward dip. To the southeast, toward the town of Lebanon, the strata are nearly horizontal. There is apparently a tendency to form a synclinal trough at this point.[a] The water from the catchment basin passing along the line of disturbance extending from the pegmatite hill to the southwest, through the lower beds of the Gasconade limestone (the

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[a] There seems to be here, as elsewhere in the Ozarks, a tendency to torsional strain, or twisting, in the flexures, which would operate to elevate the area to the south and depress that to the north. This would account for the absence of springs and the great depth of water-bearing strata to the south, as well as for the "extinct spring" at the Vernon Sink, and the immense size of the springs to the northwest.

Third Magnesian of Swallow) and the Third sandstone of Swallow below, meet the drainage from the west in this syncline, and the body of water thus gathered is forced to the surface through a crevice that has been gradually enlarged by continued erosion. A year ago a field was plowed just above this spring, and a heavy freshet washed down a large quantity of gravel which partially stopped its outlet. For several hours the water pushed itself through this obstruction in great intermittent jets, 3 or 4 feet high, with a noise that could be heard a quarter of a mile away.

Blue Spring.—About 1½ miles north of this point is Blue Spring, situated on the west side of the Niangua River. It showed a temperature of 59° F. when the air temperature was 70° F., and is at an altitude of about 900 feet. It issues from a whitish, clayey sand, and is badly choked with water cress, logs, and rubbish. The outcropping rocks indicate the middle or lower beds of the Gasconade limestone. It has a flow of 5,170,000 gallons a day.

Sand Spring.—About a quarter of a mile north of the last spring, on the same side of the river and in the same geological horizon, is Sand Spring, at about the same altitude, also badly choked with water cress, and with a flow estimated to be about the same as that of Blue Spring.

Sweet or Big Blue Spring.—This spring is in the northwest corner of Laclede County, in the NE. ¼ of the NE. ¼ of sec. 30, T. 36, R. 17, at an altitude of about 850 feet. The temperature of the water was about 58° F. when the air was 94° F. This spring issues from a vertical cave opening at the base of a bluff 40 feet high; probably the lower or middle beds of the Gasconade limestone. It has been sounded to a depth of 150 feet. The water is clear, cold, and free from weeds. It flows a distance of 150 feet westward into Niangua River. About 50 feet farther north Sweet Branch, a small, sluggish stream, empties into the Niangua. Sweet Spring is but about 5 feet above the level of the river and is subject to overflow at every rise of the stream. Situated as it is, at the junction of Sweet Branch and the Niangua, it is frequently choked with sediment from these two streams. Between the spring and the river a large area covered with treacherous mud and sand indicates that the basin of the spring was once much larger than it now is. Farmers in the vicinity state that the flow has decreased fully one-half within the last few years. The flow was calculated at 14,037,000 gallons a day. This spring lies just north of the extension of line of disturbance which runs southwestward from the Decaturville uplift.

Celt Springs.—Situated in the northeast corner of Dallas County, 7 miles northwest of Sweet Spring, are found three large springs whose waters unite to form Mill Creek. These were not visited, but they undoubtedly belong to the drainage system of the pegmatite hill.

Hahatonka or Gunter Spring.—This spring is situated 9 miles northwest of the pegmatite hill in Camden County, sec. 2, T. 37, R. 17, at an altitude of about 745 feet, or 345 feet below the height of the hill. The temperature of the water was 57° F. when the air was 88° F. The spring issues from the foot of a bluff 250 feet high, and after running for about 800 feet through a deep, narrow canyon whose walls rise at one point to a height of a little over 300 feet, it empties its waters into an artificial lake, covering 90 acres, situated in the valley of the Niangua. A small island about 100 feet high divides the stream near its outlet into the lake. The scenery in the vicinity of this spring is extremely picturesque. The spring has been sounded to a depth of about 40 feet, at which point the conduit bends to the south. The spring has its source in the Gasconade limestone, 150 feet below the base of the Moreau sandstone (Second sandstone of Swallow). It is very difficult to measure the flow of this spring, owing to the irregularities of the stream. The writer calculated 14,760 cubic feet per minute, or 158,982,912 gallons a day. A Philadelphia engineer estimated 13,800 cubic feet per minute. Professor Shaw, of the Engineering School of Missouri State University, calculated 15,000 cubic feet per minute, while Colonel Scott, an electrical engineer residing at Hahatonka, obtained the same result as Professor Shaw. The district in the vicinity of this spring possesses great interest both from a scenic and a geological standpoint. Evidences of great erosion from underground waters, showing former outlets of this great spring, are everywhere seen. At one time it doubtless had its outlet at the Big Red Sink, one-half mile to the southwest. A few hundred feet on the other side of the bluff from which the spring now issues is a sink, 150 feet deep and 600 feet long, which is open at one end and spanned by a great natural bridge. This undoubtedly marks an old cavernous channel of the great spring. In fact, most of these sinks and canyons mark the site of ancient cavernous outlets.

Cullen Spring.—This spring flows out of a bluff of Gasconade limestone, about 1 mile north of Hahatonka. Its water is clear and cold, and its flow is estimated at about 1,000,000 gallons a day.

Moulder Spring.[a]—In the northeast quarter of sec. 18, T. 38, R. 17, about 4 miles northwest of Hahatonka and about 12 miles northwest of Decaturville, is Moulder Spring, heading in a ravine about 1½ miles long that extends northward from Niangua River. The spring boils up strongly from a bed of coarse gravel 25 feet in diameter, and is estimated by Colonel Scott to be about one-sixth the size of Hahatonka Spring. It issues from the Gasconade limestone, and has its head in the tilted beds which surround the pegmatite hill.

Toronto Springs.—At Toronto, 6 miles northeast of Montreal, in the SW. ¼ of the NE. ¼ of sec. 25, T. 38, R. 15, are several large springs that boil up with great force out of gravelly beds in the Gasconade limestone, flow eastward a short distance, and empty into Auglaize River.

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[a] The writer was unable to visit either Moulder, Cullen, or Toronto springs, all probably belonging to this system, and is indebted to Colonel Scott, of Hahatonka, for data concerning them.

Wet Glaize Springs.—These are two fine springs situated in the NE. ¼ of sec. 24, T. 37, R. 15, about 8 miles a little north of east of Decaturville. One is located near the foot of a bluff of Gasconade limestone 40 feet high, and the other, which is the larger of the two, is about 300 feet farther east, rising from a gravel bed at about the same level. A dam 16 feet high forms a pond of about 10 acres, which covers these two springs. As the pond had been lowered and the gate closed just before the writer arrived at these springs it was impossible to measure their flow, but from what could be learned in regard to them it is probable that their capacity is about 40,000,000 gallons a day. As described by their owner, they both boil up with considerable force out of gravel beds, rolling and tossing up large pebbles. Their location can be marked on the surface of the pond from the disturbance of the waters. They also receive their supply from the catchment basin around the pegmatite hill and the cavernous Gasconade limestone, which, with the Third sandstone of Swallow, forms a great reservoir for all this spring system. Their altitude is about 825 feet, or 265 feet below the outcrop of pegmatite.

Camp Ground Spring.—This spring is located about one-half mile south of the Wet Glaize Springs. A large basin has been hollowed out from the side of the hill by this spring, which boils up from a bed of gravel in a remarkable manner. It issues from a number of holes about 5 inches in diameter, raising and tossing the gravel with great force and making the surface of the spring somewhat resemble a cauldron of boiling water. The water temperature was 55° F. when the air was 84° F. The flow could not be determined, owing to the masses of water cress that choked the outlet. It is stated that it takes thirty-six hours after a heavy rain for this spring to show an increase in its flow.

Armstrong Springs.—These are situated about 9 miles a little south of east of Decaturville, and are at an altitude of about 895 feet.

Ella or West Spring.—This is located in the NW. ¼ of the NE. ¼ of sec. 6, T. 36, R. 14. The temperature of the water was 56° F. when the air was 86° F. The water boils up powerfully from holes in the rock, one of which, 3 feet in diameter, has been sounded to a depth of 30 feet. A bluff of Gasconade limestone, 50 feet high, outcrops just above this spring. The flow was calculated to be 19,112,896 gallons a day. About 12 hours after a heavy rain the volume increases, and the waters become slightly turbid.

Lizzie or East Spring.—This rises from a deep, narrow gorge, on the side of the valley opposite the Ella Spring. Its flow was estimated to be about 3,000,000 gallons a day. The temperature of the water was 56° F. when that of the air was 90° F.

SINKS.

Vernon Sinks.—About 8 miles a little east of south of Decaturville are several sink holes of considerable interest. These lie in a line away from the pegmatite outcrop, in sec. 18, T. 35, R. 15. The main, or Vernon Sink, is about 120 feet in diameter, and about 50 feet deep to the water level. In very dry times the water level sinks 40 feet and exposes a cave-like opening that extends 300 feet or more on an incline due west. A drill well was sunk about 200 feet west of this sink to a depth of 60 feet, and reached the cave opening. A pump was inserted, and the water obtained is constantly used, being clear and cold and never muddy or turbid. It is possible that this may be the mouth of a former outlet of the Decaturville system of springs, the water level standing at an altitude of about 1,080 feet, 10 feet below the catchment basin. Some of the enormous springs in southern Morgan County, and in western Miller and Pulaski counties, possibly belong to this system, and will furnish interesting material for future study.

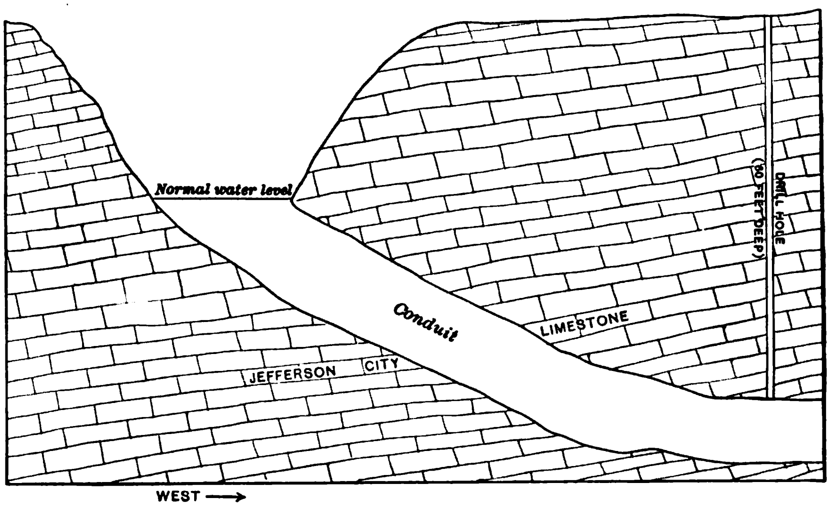

FIG. 31.—Diagrammatic cross section of Vernon Sink.

ARTESIAN WELLS.

In addition to the springs that have been described, artesian wells may be expected in this district wherever the general surface of the country is sufficiently below the level of the catchment basins. Mr. J. N. Kennett, of Decaturville, sunk a drill hole 300 feet for ore one-third of a mile northeast of the pegmatite hill and 40 feet lower than that elevation. A weak flow of water was struck at 200 feet. On the south edge of Hahatonka Lake, Colonel Kellogg sunk a drill hole for mineral to a depth of 864 feet. Water rose in this pipe 30 feet above the ground and threw a jet 6 feet higher. The strong flow was struck at 840 feet, but the force has gradually decreased until the water only flows gently over the pipe at the surface of the ground. This water is slightly charged with sulphuretted hydrogen. It is to be noted that elsewhere artesian wells from this formation are strongly saline, and highly charged with sulphuretted hydrogen, the absence of which in this region is significant of one of the great changes wrought by powerful underground drainage. The Rush artesian well, on the west side of Banks Creek, about 2 miles southwest of Hahatonka and at about the same altitude as the Kellogg well, was sunk to a depth of 780 feet. Water rises 30 feet above the ground, the first flow having been struck at 630 feet. The water temperature is 59° F. when the air is 84° F. There is a slight odor of sulphur. The flow of this well has never decreased. The Scott well, one-eighth of a mile north of the Rush well, on Banks Creek, was sunk to a depth of 740 feet. The first water was struck at 680 feet, and it flows only slowly from the pipe at the surface of the ground. The last three wells all passed through beds of siliceous limestone, only the Kellogg well entering sandstone (Third sandstone of swallow) to a depth of 3 feet. These wells show the enormous thickness of the Gasconade limestone at this point. Another artesian well, situated in the big bend of the Osage, in the NW. ¼ of sec. 22, T. 40, R. 18, was sunk to a depth of 800 feet, and obtained a strong flow of water. This well was not visited, but it probably belongs to the Decaturville drainage system.

SURFACE WATERS.

The region around Decaturville, bounded by Bennett, Sweet, Hahatonka, Wet Glaize, and Armstrong springs, is almost destitute of surface water, the inhabitants being dependent for their supply upon ponds, cisterns, and a few drilled wells. For example, Mr. Haun, who lives between Sweet Spring and Decaturville, drilled 130 feet, and has only from 3 to 6 feet of water, which is quickly pumped dry. The little town of Eldridge, nearby, is wholly dependent on cisterns and ponds for water. Mr. F. M. Cossairt, at Chauncey, Camden County, 6 miles due north from Decaturville, sunk a well 144 feet deep, and struck water at 119 feet, at which level it remains. He states that wells in this vicinity reach water at depths ranging from 100 to 125 feet, and generally have to go to sandstone. At Lebanon, 15 miles due south of Decaturville, in a well sunk to a depth of 1,000 feet, the water stands 360 feet below the surface. About 5 miles west of Lebanon, at nearly the same altitude, a farmer sunk a well 420 feet deep, in which water stands 400 feet below the surface. A pump can not lower it.

COMPOSITION OF SPRING WATERS.

Partial quantitative analyses of a number of the springs of the Decaturville system show a nearly uniform composition quite similar to that of the Lebanon "Magnetic" well, except in a slight increase in chlorides.[a]

The following is the analysis of the Lebanon well, made by Mr. L. G. Eakins, of the U. S. Geological Survey:

Analysis of water from Lebanon well.

	Parts per million.
Silica	11.2
Alumina	32.0
Sodium chloride	Trace.
Magnesium sulphate	6.0
Ferrous carbonate	Trace.
Calcium carbonate	81.1
Magnesium carbonate	52.8
Sodium carbonate	29.1
Total solids	212.2
Free carbonic acid	69.8

CHERT BEDS.

One of the most interesting deductions drawn from the study of the underground waters of this region is their probable connection with the origin of the enormous beds of chert that occur here. Though this point can be but briefly touched upon at this stage of the investigation, it should not be left without notice. All who have visited this region have observed its wonderful deposits of chert, particularly in the Jefferson City and Gasconade limestones. These formations are usually largely dolomitic, particularly the Jefferson City limestone, which contains large masses of dolomite ("cotton rock"). In the district surrounding Decaturville, however, the dolomite is almost entirely absent, and beds of chert seem to have taken its place, especially above and below the sandstone horizons. The chert beds are of great thickness, and are composed of knotted, irregular, frequently lenticular, sometimes agatized, shattered masses. Frequently these shattered masses are recemented into chert breccias. The shattering and cementing by resilicification of the chert beds in many places is another evidence of the second uplift, before referred to, in this region.

The writer has long believed that many of our chert deposits have been formed by replacement, and the evidence in this district points strongly to this conclusion. Briefly, it may be stated that during the period of the uplift of the pegmatite boss, the great heat generated was retained by the superincumbent beds (since eroded), and that percolating water, intensely heated, aided by the alkalies derived from the decomposed feldspar and lime, dissolved from the rocks their silica, which gradually replaced the lime and magnesia in the dolomites and converted them into cherts. This replacement seems to have been especially marked above and below the sandstone horizons—so much so as to make it very difficult to separate the Moreau sandstone from the Gasconade limestone below, and the Gasconade limestone from the Gunter sandstone, by which it is underlain, for the reason that the Gasconade limestone merges, through massive chert beds, into the sandstone horizons, both above and below. This is so strikingly the condition in Miller County that State Geologist Buckley, in his report on Miller County, now in press, includes the Moreau sandstone (Second sandstone of Swallow), a part of the Jefferson City limestone (Second Magnesian of Swallow), and part of the Gasconade limestone (Third Magnesian of Swallow) in one formation, which he has named the St. Elizabeth formation, or complex.[a] It will be noted that this special chert replacement predominates along the main line of water flow on both sides of the sandstone horizons.

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[a] The presence of sodium carbonate in the waters of this district—an unusual occurrence elsewhere in these formations—is significant of its probable source from the albite (soda feldspar) of the pegmatite; and the same fact also calls attention to the probable magnitude of the pegmatite boss.

The study of the Decaturville dome has led the writer to believe that the association of massive chert beds with several other great spring districts in the Ozarks has a deeper significance than that which is usually recognized in considering these beds as merely the reservoirs or channels for the distribution of underground waters, and it is hoped that this brief sketch may throw some light on the origin of the chert beds, as well as emphasize the importance of underground drainage as a geologic agent.

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[a] See also Biennial Report of the State Geologist of Missouri to the Forty-second General Assembly, Jefferson City, 1903, p. 14.

WATER RESOURCES OF FORT TICONDEROGA QUADRANGLE, VERMONT AND NEW YORK.

By T. Nelson Dale.

INTRODUCTION.

Geography.—The Fort Ticonderoga quadrangle is located on the Vermont-New York boundary line, about midway of the length of Vermont. Three-fourths of its area is in Vermont and the remainder in New York. It comprises four small quadrangles—the Ticonderoga, Brandon, Whitehall, and Castleton—each of which contains about 225 square miles. The area includes considerable portions of Rutland and Addison counties, Vermont, and of Essex, Warren, and Washington counties, New York. The principal towns are Ticonderoga and Whitehall in New York, and Proctor, Brandon, Poultney, Fair Haven, and West Rutland in Vermont.

Relief.—The relief of the region varies from an altitude of 100 feet near the shores of Lake Champlain to over 2,700 feet a few miles southwest of West Rutland. Roughly it may be divided into three belts—an eastern belt lying mainly east of a line extending from East Middlebury, through Bomoseen Lake, to Poultney; a middle belt lying between the eastern belt and Lake Champlain, and a western belt, west of Lake Champlain. The first includes the northern end of the Taconic Range, which consists of high, irregular ridges and isolated hills, several points of which reach 2,000 feet or more, and one, Herrick Mountain, rises to over 2,700 feet. It includes also in its northern half a part of the west side of the Green Mountain Range, consisting of ridges, with Mount Moosalamoo rising to over 2,600 feet. In the second belt the land generally varies from 100 to 1,000 feet in altitude. Many extensive terraces are developed at altitudes between 300 and 550 feet. Above these many hills rise to a level of 1,000 feet or more Much of the area is covered by a considerable thickness of drift which has much modified the topography of the region. The third belt is mountainous, with maximum elevations varying from 1,400 feet in the northern part of the area to 1,900 feet in the southern part. The major features of the topography are due to rock structure or composition, but some are due to ice action or to Glacial or post-Glacial deposits.

Drainage.—The drainage of the southern half of the area is westward to Lake Champlain and then northward to the St. Lawrence. In the northern half it is northward by Lake Champlain and Otter Creek. Two other considerable streams—the Middlebury and Leicester rivers—besides Mill Brook, a smaller stream farther south, issue from the mountains and empty into Otter Creek. These streams drain a considerable region lying east of the quadrangle, and comprise the output of innumerable forest springs and rivulets.

WATER SUPPLIES.

General conditions.—The southern half of western Vermont is generally well watered, both because of a copious rainfall and because of the presence of two mountain ranges—the Taconic on the west and the Green Mountain on the east—which are both well wooded and drained by numerous brooks. As the Taconic Range ends in about the center of the quadrangle, one of the chief sources of water supply there ceases, the conditions becoming very different farther northward.

The western border of the Green Mountain Range, with the exception of certain deforested tracts in Goshen and minor clearings in Ripton, is densely forested, and is therefore rich in springs and brooks, so that the question of water supply in the eastern third of the quadrangle is rarely a serious one. In fact, no one familiar with this area can fail to be impressed with the abundance and purity of the water.

Cold springs and brooks.—Some of the water is unusually cold. About three-fourths of a mile southwest of Brandon village is a well dug in a mass of glacial gravel, the pebbles of which are cemented together by calcium carbonate, forming a quasi conglomerate. This well has long attracted attention on account of the very low temperature of its water throughout the summer months, and has also been investigated by geologists.[a] It is known locally as "the frozen well."

As pertinent to this subject, although belonging to the Mettawee quadrangle, the following data are added: Three-fourths of a mile northwest of the top of Dorset Mountain and 1,700 feet below it, in the township of Danby, is a brook of crystal purity, in which the temperature on September 22, 1891, was but little above that of ice water. As the top of Dorset Mountain is only 3,804 feet high the following explanation was adopted: The summits of the Taconic range usually consist of shattered schist ledges covered with thick moss and forest. Ice formed between the blocks in winter may be protected by the dense vegetation and may be the source of such ice-water brooks. Ice-water springs also occur occasionally at the foot of exposed, sun-heated slate-quarry dumps in Washington County, N. Y., in places where no mountain drainage could possibly come. These springs also maintain a low temperature throughout the hot summers. Another brook of low temperature, known as Cold Brook, occurs 3½ miles southeast of Dorset Mountain, in Dorset Hollow. On July 20, 1900, a very hot day, it was cold enough to form a mist about itself. It issues from a limestone cave, through which its course lies for one-half to one-fourth of a mile, and which is at times presumably more or less filled with snow or ice.

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[a] See Hitchcock and Hager, Rept. Geol. Vermont, vol. 1, 1861, pp. 192-208.

Town supplies.—Because of the vitiation of the water, owing to the building of towns, as in the case of the portion of Otter Creek below Rutland and Proctor, streams are no longer safe sources of drinking water. This has been amply demonstrated by the prevalence of typhoid at Middlebury, just north of this quadrangle, as long as Otter Creek water was used, and by its cessation as soon as that use ceased. Where springs or brooks are not available, shallow wells, especially in the lowlands, usually obtain sufficient supplies. The practical utilization of springs as a source of water supply has been demonstrated within a few years at two points north and south of this quadrangle. Water has been brought from a spring on Niquaket, a mountain a mile north-northeast of the southeast corner of the quadrangle, through pipes for a distance of over 4 miles to the village of Pittsford, which is located on a sandy terrace 130 to 150 feet above Otter Creek. A similar system now supplies the village of Middlebury with water from a spring on the Green Mountain range. But for the use of Silver Lake (altitude 1,241 feet) as a summer resort, it would be admirably adapted for a similar purpose, as it is a natural reservoir fed by forest mountain springs.

Geology of the supplies.—The geologic structure of Otter Creek valley seems unfavorable for artesian wells because the marble and dolomite beds, which underlie its gravel and clay, generally lie in small and overturned folds. It is possible, however, that borings which should penetrate that formation (1,000 feet or more thick) and the underlying quarzite and schist (1,600 feet or over) to the basal gneiss of the Green Mountain range (pre-Cambrian) might be productive.

There is a longitudinal belt about 7 miles wide, measured westward from the foot of the Green Mountain range, underlain by dolomite and marble, in which any wells reaching those beds would inevitably furnish water more or less calcareous. There are also on the Green Mountain range areas of dolomite which would have a like effect. Such an area covers about 6 square miles at the southeast corner of the quadrangle. A narrow strip of dolomite extends also 5 miles from Sucker Brook south, inclosing Silver Lake, and must needs add a small percentage of lime to the tributaries of Mill and Sucker brooks. The rocks of the Green Mountain range, with rare intercalations of dolomite, are in other places quartzose, micaceous, and feldspathic, and are thus adapted to furnish the very best of water, except where springs or brooks drain extensive swamps and add organic matter. The occasional disappearance of brooks into caves in the limestone areas is a factor which should be taken into consideration in some of the hydrographic problems.

In the lower levels of the towns of Orwell, Whiting, and Cornwall, along the western edge of the quadrangle, plastic clays, which probably formed the sea bottom of the Lake Champlain region during the "Champlain submergence," introduce conditions very different from those prevailing along the foot of the Green Mountain range, where the superficial deposits are generally more sandy. The effect of these impervious clays, together with that of deforestation in the last generation or two, has been to bring about great scarcity of water. This is very apparent in the northern part of the middle belt, where driven wells, reaching to or into the shales underlying the clays and operated by windmills, are a necessity on many farms, and where the rarity of public watering troughs on the highways is as marked as the poverty of the brooks.

Water power.—East Middlebury River, Mill Brook, and Leicester River have long been utilized in a small way for driving sawmills and other wood-working machinery, etc. The fall of all these streams is considerable. Middlebury River falls 517 feet between Ripton and East Middlebury, a distance of not quite 3 miles. Leicester River, the outlet of Lake Dunmore, falls 171 feet in its course of 1¼ miles from the lake to Salisbury village. Mill Brook falls 636 feet between Goshen and Forestdale, a distance of 3 miles. Besides the above, and as yet not utilized for power, there is Sucker Brook, which has a fall of 529 feet in a distance of 1½ miles above Lake Dunmore. Silver Lake, the outlet of which flows into Sucker Brook, is 670 feet above Lake Dunmore. The narrow gorges through which these streams flow and their greatly swollen condition in spring offer difficulties, however, which must be considered in any scheme for their complete utilization.

WATER RESOURCES OF THE TACONIC QUADRANGLE, NEW YORK, MASSACHUSETTS, VERMONT.[a]

By F. B. TAYLOR.

INTRODUCTION.

Geography.—The center of the Taconic quadrangle falls almost exactly on the point at which the States of New York, Massachusetts, and Vermont come together. The area included is about 35 miles long from north to south, and 20 miles wide from east to west, containing a little over 900 square miles. The region lies mainly in Rensselaer County, N. Y., Berkshire County, Mass., and Bennington County, Vt. North Adams, Mass., Bennington, Vt., and Hoosick Falls, N. Y., are the leading towns.

Relief.—All of the land of the quadrangle is moderately high, except along the larger streams, where it is sometimes as low as 350 feet above sea level. The area is mountainous, except in the western third, the ranges having a trend a few degrees east of north. The principal mountain masses are the Hoosac on the east, rising to a maximum height of about 2,800 feet, Greylock, and the Green Mountains in western Massachusetts and Vermont, rising to heights of from 2,500 to 3,700 feet, and the Taconic Mountains, along the New York boundary line, rising from 2,200 to 2,800 feet. The western third of the quadrangle partakes of the nature of a compound plateau, the northern portion standing at an altitude of from 800 to 1,200 feet, and the southern at from 1,500 to 1,800 feet. The topographic expression of the region depends to a considerable degree upon the structure and composition of the rocks.

Drainage.—The drainage of nearly the entire area of the quadrangle is by the Hoosic River northwestward to the Hudson River above Troy. A small area in the southwest portion, however, drains southwestward to the Hudson, 25 miles below Albany.

WATER RESOURCES.

SURFICIAL WATERS.

The surface waters include all the running and ponded surface waters which result from rains and melting snows or which are fed by springs.

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[a] The field work on the surficial geology of this quadrangle is only about half completed, the unfinished part being confined mainly to the western half. The conditions as regards water supply are, however, much the same throughout the area.

Rainfall.—The mean annual rainfall of this area is about 42 inches, but the rainfall varies by 35 to 40 per cent of this amount between extremes in different years.

Water power.—The relief of this area is considerable, the altitudes ranging from 3,764 feet above tide on Glastenbury Mountain, and 3,505 feet on Greylock Mountain, to about 300 feet above tide on Hoosic River, where it passes out of the quadrangle. Many of the smaller streams descend 1,500 to 2,000 feet in a few miles and afford excellent opportunities for the development of small water powers. The mountains are mostly forest clad, so that the run-off of rain water is somewhat checked and opportunity is afforded for its absorption into the glacial drift, and to some extent into the rocks. The drift, though patchy and irregular in thickness and distribution, covers most of the surface, except the steep slopes and the highest knobs and ridges. In a general way the drift is slightly coarser and more porous on the mountains than in the valleys. The rocks—mainly gneisses, quartzites, and schists in the mountains—are not of themselves porous enough to absorb much water, but they are cut by numerous joint cracks, and some of the rainfall finds its way into these, from which it issues in springs. The great number of perennial mountain brooks shows that the drift and the rocks are effective reservoirs for water storage.

The Hoosic, the largest river, crosses the quadrangle diagonally from southeast to northwest. It descends within the area from an altitude of about 1,100 feet above tide to 300 feet. The principal water powers on this river are at Adams, North Adams, and Hoosick Falls, though there are several others at smaller villages, such as Cheshire, Braytonville, Blackinton, Williamstown Station, and North Pownal. The other principal water powers in this area are on the Walloomsac at Bennington, Papermill Village, and North Hoosick; on Paran Creek at North Bennington; on Green River at Williamstown, and on the north branch of the Hoosic at Briggsville and in North Adams. Small powers are also used at Hancock and Garfield on Kinderhook Creek, at Berlin and Petersburg on the Little Hoosic, and at South Shaftsbury on Paran Creek. Besides these there are a great many smaller developments of power for private use in all parts of the area. Many farmers utilize brooks for power to run dairy and grinding machinery. The demand for power on the rivers is greater than the supply, so that even when the streams are at more than their average volume the supply is insufficient for the mills of the larger towns. In dry seasons the supply is much reduced, but does not fail altogether.

Lakes and ponds.—Natural ponds are not so numerous in this area as in some other parts of New England. There are about 30, large and small, shown on the map, and some artificial ones also. Only two or three are as long as 1 mile. The largest is Pontoosuc Lake, on the southern boundary, but this lies mostly outside of the quadrangle and its outlet is southward. The level of many ponds has been raised by dams so as to increase their capacity as reservoirs, and other reservoirs have been made by damming narrow valleys. The largest reservoir, which is just south of Cheshire, is 3 miles long and one-fourth to one-third of a mile wide.

City and domestic water supplies.—So far as known all the cities and most of the villages get their water supply from mountain brooks. Some farmers get their water from brooks, but most of them derive their supply from springs.

UNDERGROUND WATERS.

Except so far as revealed by springs, nothing is known of the distribution or quality of the underground waters of this area. The water of the mountain springs, whether issuing from drift or from the rock, is generally of excellent quality. No bored wells have yet been noted within the area and dug wells are few. Those seen were all sunk into the drift, generally to depths less than 20 feet. In the relatively low area north and west of Bennington and Hoosick Falls wells are probably more common, but most of this area remains to be investigated. In a general way the character of the rocks and the geologic structure seem to afford no certain promise of success in boring artesian or flowing wells. The artesian wells at Dalton, a few miles south of this quadrangle, appear to flow from a great fault crack which was struck accidentally by an experimental boring.

Mineral springs.—The only important mineral spring thus far noted is Sand Spring, on the north side of Broad Brook, about 1½ miles north-northwest of Williamstown station. The following information relating to this spring was obtained from Dr. S. Louis Lloyd, who owns the spring and runs a sanitarium and baths at that place. The spring boils up through white sand and flows 400 gallons a minute without noticeable variation, even during periods of extreme drought. The temperature of the water is 76° F. winter and summer. Its purity and mineral contents give it valuable medicinal properties for both drinking and bathing. A circular issued by the proprietor gives the following analyses, made by Leverett H. Mears, professor of chemistry in Williams College:

Chemical analysis of water of Sand Springs.

	Parts per 100,000.
Lithium chloride	0.0353
Sodium chloride	.0768
Acid calcium carbonate	3.2249
Acid magnesium carbonate	2.6479
Calcium sulphate	.7262
Aluminum sesquioxide	.0325
Iron sesquioxide	.0075
Silica	.7026
Sodium carbonate	.4641
	7.9178

Sanitary analysis.

		Parts per 100,000.
Color, odor and sediment		None
Solids	Total	12.6200
	Volatile	2.4600
	Fixed	10.1600
Chlorine		.1300
Ammonia, free		.0000
Ammonia, albuminoid		.0018
Nitrogen as nitrites		.0000
Nitrogen as nitrates		.0152

Gas analysis.

Carbon dioxide	.30
Oxygen	11.34
Nitrogen	88.36

This spring issues from the drift-covered slope north of Hoosic River and stands somewhat more than 100 feet above it. It appears to lie almost directly in line with a prominent fault which runs north and south along the east side of Mason Hill in Vermont, emerging a little more than a mile south of the point where the fault passes from view under the drift. Considering its relatively high temperature, its constancy of volume and temperature, and its mineral properties, it seems probable that the water of this spring comes from the fault and hence from a deep-seated source.

There may be other mineral springs in the quadrangle, but none are known at present.

INFLUENCE OF WATER SUPPLY ON SETTLEMENT.

The presence of water power has been the main influence in locating the cities and villages of this area. Four cities—Adams, North Adams, Hoosick Falls, and Bennington—all owe their location to this cause, and the positions of most of the villages have been determined by the same influence. Farmhouses in this area are usually located with reference to convenience of access to some spring or brook. The area is comparatively poor in agriculture. Except in the northwestern part, the valleys are narrow and the hill farms are generally stony and barren. With the decline of agriculture, farmers had to find other ways of making a living. Many of them—the hill farmers especially—have met the difficulty by keeping "city boarders," and most of them have found it profitable, as is abundantly proved by the better appearance of their places. The region is justly famed as a summer and autumn resort for health and pleasure, and the prosperity of a considerable part of its population depends much upon the annual coming of visitors. Pure drinking water and the scenic charms of clear, rapid, mountain brooks constitute important factors among the many attractions that draw summer visitors to this region.

WATER RESOURCES OF THE WATKINS GLEN QUADRANGLE NEW YORK.

By Ralph S. Tarr.

LOCATION AND DRAINAGE.

The Watkins Glen quadrangle is located in south-central New York, and includes the areas mapped on the Elmira, Waverly, Watkins, and Ithaca topographic sheets of the United States Geological Survey. In it are located Elmira, Ithaca, and a number of smaller cities and towns. It is crossed by a portion of the divide that rises between the Oswego and Susquehanna drainage systems, and includes some of the headwaters of each system. Chemung River crosses the Elmira and Waverly quadrangles in the southern part of the area, carrying through Elmira the drainage of 2,055 square miles of country. Next in size to the Chemung Valley are the two northward sloping valleys occupied by Cayuga and Seneca lakes, with drainage areas of 1,593 and 707 square miles, respectively. Throughout the quadrangle one effect of glaciation has been to cause changes in divides, which have turned streams from one drainage area into another. As a result, many of the streams flow in valleys that are out of proportion to the volume of water they carry; some large valleys contain small streams, some large streams flow in small valleys. This condition has an important bearing on the distribution of underground water, whose direction of movement may consequently often be directly opposite to that of the surface water.

None of the streams of this area are of value in navigation; but the Chemung Valley was the site of a canal, now abandoned after having been operated at a loss. Both Cayuga and Seneca lakes are seats of navigation, but this shared the decline of the Erie Canal, with which the lakes are connected by short branch canals. Many hydrographic problems connected with these lakes have not yet been investigated.

The overdeepening of the two lake valleys, possibly by ice erosion, has left the tributaries hanging far above the level of the lakes. In descending to lake level the tributaries therefore have high grades, and in the short time since the Glacial epoch have been unable to do more than form steep-walled gorges through which the water flows in a series of rapids and falls. These gorges, falls, and rapids are exceedingly picturesque, and in the case of Taghanic Falls, Watkins Glen, and Havana Glen, have won wide reputations. The water power of some of these streams is used for running grist and other mills; that of Fall Creek furnishes power for generating the electricity used at Cornell University and gave opportunity for the construction of the hydraulic laboratory. Through general deforesting the value of the streams for purposes of power is decreasing.

WATER SUPPLY.[a]

The surface streams are used by the towns in the area as a source of municipal water supply, in some cases, as at Ithaca and Elmira, after filtration. The need of such filtration was forcibly impressed upon the people of Ithaca by an epidemic of typhoid fever in 1903, which resulted from the pollution of creek water, then supplied unfiltered. All the surface waters are notably hard, as the following analyses show. The hardness results from the solution of lime and other salts from the shales and from the glacial deposits, which consist in large measure of ground-up shale and limestone. So much lime is at times carried in solution that springs, on emerging, precipitate it, forming deposits of calcareous tufa.

The condition of this surface water is clearly illustrated by the following analyses of two creeks whose mouths only are within the Watkins quadrangle, but whose waters have been studied with especial care because of their relation to the Ithacan water supply.

Results of examination of water from Fall Creek at Ithaca.

[Parts per million. Prof. E. M. Chamot, analyst.]

Date.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Hardness (alkalinity).	Carbon dioxide.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1903.									
February 13	35.00	....	0.071	0.031	Tr.	2.08	......	......	......
February 14	55.00	....	.071	.031	Tr.	1.82	......	......	......
February 16	33.00	....	.078	.023	Tr.	1.54	2.25	65.8	1.24
February 17	18.00	....	.094	.028	0.002	1.35	1.25	80.1	2.24
February 18	24.00	....	.082	.016	.002	1.818	1.50	80.1	1.714
February 19	22.00	....	.062	.023	.002	1.667	1.50	84.7	2.19
October:[b]									
Maximum	42.00	150.00	....	....	....	....	......	103.0	......
Minimum	.25	13.00	....	....	....	....	......	55.0	......
November:[b]									
Maximum	10.00	104.00	....	....	....	....	......	108.8	......
Minimum	.25	13.00	....	....	....	....	......	63.8	......
December:[b]									
Maximum	1.00	25.00	....	....	....	....	......	115.0	......
Minimum	.20	6.00	....	....	....	....	......	87.5	......

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[a] I take pleasure in acknowledging the assistance of Mr. Lawrence Martin in obtaining data concerning the water resources; of Mr. C. C. Vermeule, engineer for the Ithaca water board, and his assistant, Mr. Getman, who supplied me with carefully kept records and samples; and of Prof. E. M. Chamot, of Cornell University, for analyses and other information about the chemical features of the problem.

[b] Daily observations.

Results of examination of water from Sixmile Creek at Ithaca.

[Prof. E. M. Chamot, analyst.]

	Raw water before filtration.											
	Bacteria per c. c.			Turbidity.			Color.			Alkalinity.		
	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.
1903–4.												
October....	7,220	36,000	850	(*a*)	1,800	0.25	45	128	2.5	81	134.0	45.0
November .	5,460	23,000	800	31	160	.8	63	160	18.0	82	92.5	60.0
December..	2,900	8,600	900	8	35	.75	33	85	14.0	89	97.5	80.0
January ...	6,200	520,000	1,000	13	2,500	5.0	14	40	10.0	76	100.0	45.0
February ..	13,400	97,000	1,500	46	400	6.0	11	24	4.0	72	85.0	35.0
March	28,600	115,000	2,500	220	3,000	5.0	13	24	5.0	57	87.5	40.0
April.......	7,330	50,500	1,500	104	400	40.0	11	20	5.0	54	67.5	37.5
May........	7,300	35,000	450	40	500	10.0	13	24	5.0	72	95.0	55.0
June	7,500	62,000	450	47	250	7.0	15	34	6.0	94	125.0	60.0
July........	1,050	6,500	350	57	95	28.0	9	27	3.0	127	130.0	120.0
August.....	2,400	18,000	400	76	200	45.0	20	45	1.0	127	140.0	110.0
September .	1,200	2,800	500	57	80	18.0	9	20	3.0	131	140.0	125.0
Average ...	7,550	....	....	58	....	....	21	....	....	91	....	....

[a] Too variable to average.

It goes almost without saying, that springs and wells are common in this area, and that their waters resemble in hardness the creek waters at low stage. Many of the wells, especially on the hill farms, are in rock; others are in glacial drift; and some are in post-Glacial deposits. Most of the shallow wells show decided fluctuation with season. The most copious springs occur in the regions of outwash gravels and near the margins of alluvial fans, into which the stream water often sinks, reappearing as springs.

In a number of places in the area there are deep wells in which the water rises nearly or quite to the surface. This is true, for example, just south of Watkins, at Montour Falls, near Breesport, and in the outwash gravels in and near Elmira. In only one place, however, have the water resources of the glacial deposits been extensively exploited, namely, at Ithaca. Prior to the introduction of a city water supply the town of Ithaca depended upon wells, and even at the present time many of these are in use. Some of these are shallow dug wells that receive the drainage of a densely populated hill slope. Others are in gravels of alluvial fans, built where Sixmile and Cascadilla creeks emerge from their gorges upon the Ithaca delta plain. Many of the Ithaca wells are, however, driven, and furnish artesian water. The depth which these wells reach varies, being in most cases from 80 to 100 feet, and in some of the wells the water has head enough to permit piping to the second floor. They are both overlain and underlain by an extensive stratum of clay. In the table following the first seven analyses show the general character of this water.

Sanitary analyses of well waters at Ithaca.

[In parts per million. Prof. E. M. Chamot, analyst.]

No.	Location of well.	Date.	Depth of well.	Turbidity.	Color.	Odor.	Total solids.	Loss on ignition.	Total hardness.	Alkalinity.	Chlorine.	Free ammonia.	Albuminoid ammonia.
		1903.	*Feet.*										
1	Tompkins street	June 13	100							260.0	27.0		
2	Utica street	Mar. 19	80							197.5	32.6		
3	Wood street	July 7	120							140.0	59.0		
4	Madison street	Apr. 3	85							135.0	14.8		
5	Plain (South) street	July 7	96							100.5	16.0		
6	Adams street	June 15	100							165.0	39.5		
7	Albany (South) street	July 7	104							155.0	60.0		
8	Salt works well	Feb. 17	120	None.	None.	H_2S	314.5	109.5	176.5	145.8	38.5	0.083	0.013
9	Illston well	Feb. 7	280	None.	Slight.	H_2S			200.0	197.5	45.0	.565	None.
		1899.											
10	Do	Apr. 10	280	None.	Slight.	H_2S	304.0	78.0			61.6	.480	.005

Sanitary analyses of well waters at Ithaca—Continued.

No.	Location of well.	Date.	Nitrogen as nitrites.	Nitrogen as nitrates.	Oxygen consumed.	Bacterial colonies.	Growth in phenol-peptone-glucose.	Behavior in Dunham solution.	Remarks.
		1903.							
1	Tompkins street	June 13	0.0004	None.	1.375	1,800	Coli-like; gas	Uniformly turbid; strong indol.	
2	Utica street	Mar. 19	.005	0.45	1.40	1,440	Slight; gas	Coli-like; very foul; strong indol.	Sunk in 1896. Flows in cellar.
3	Wood street	July 7	None.	None.	.425	12	No growth	No growth	CO_2=5.0. Flows.
4	Madison street	Apr. 3	None.	Trace.	1.30	70	Weak; no gas	Slight turbidity; no indol.	CO_2=5.0. Flows. Sunk about 1878.
5	Plain (South) street	July 7	None.	None.	.675	430	Vigorous; gas	Turbid; indol	Driven.
6	Adams street	June 15	None.	Trace.	.50	10	No growth	No growth	Flows.
7	Albany (South) street	July 7	None.	None.	.525	46	None	do	CO_2=4.5. Flows in cellar.
8	Salt works well	Feb. 17	None.	None.	.450	25			CO_2=6.
9	Illston well	Feb. 7	None.	Trace.	.450				CO_2=3.309.
		1899.							
10	Do	Apr. 10	None.	Trace.	.644	10	No growth	Very slight turbidity.	

Toward the western side of the valley a well, 120 feet deep, known as the "Fourth street well," was drilled by a committee of citizens during the typhoid epidemic. The flow of water from it was estimated to be about 100,000 gallons a day. Near it is a well to the same water-bearing bed, which is pumped by a salt company for use in dissolving salt to form brine. It yields from 300,000 to 400,000 gallons a day by pumping. Its composition is shown by analysis No. 8, in the accompanying table. Just south of the city, near the western side of the delta plain, 2 deep wells have been put down by a committee of citizens, and 11 by the Ithaca water board. These 13 wells are not far apart, and most of them are very near an artesian well, known as the "Illston well," that was bored several years ago. This well showed a flow of over 300,000 gallons a day, by weir measurement, in the spring of 1903. Two of the wells reached rock, one at a depth of 260 feet, the other at a depth of 342 feet. Of the 13 wells, 9 are flowing, and the engineer of the water board estimates that they have a total capacity, when pumped, of between 2,000,000 and 3,000,000 gallons daily, which is more than ample for the city of Ithaca. A number of wells are clustered around the Illston well, and reach the same water-bearing series at a depth of about 280 feet. That the various wells tap the same water-bearing layers is evident from their influence upon one another. The pressure in the Illston well, for example, is reduced from 18 to 12 pounds when all the adjacent wells are flowing. Whether the estimated capacity of the wells will be actually reached when all the wells have been pumped for a while remains to be seen.

These 14 wells reveal a set of conditions in the Ithaca delta as follows:[a] Below an upper series of beds of soil and muck about 10 feet thick is a bed of clay varying in thickness from place to place and underlain at depths ranging from 60 to 90 feet by water-bearing sands and gravels that vary in thickness from 30 to 60 feet. Beneath the sand and gravel is a great depth of uniform clay, attaining a thickness of 120 to 150 feet. Then sandy clays, quicksands, sands, and gravels are encountered. Even in wells drilled but a few feet apart the sections through the water-bearing layers differ, as one would expect in glacial sands and gravels. This variation makes well boring very uncertain. Several of the wells reached a quicksand so filled with water and under such pressure that it rose in the pipe faster than it could be removed. The more successful wells reached either gravel, or sand with gravel, from which the sand could be jettied out, leaving a protecting mass of pebbles around the pipe mouth. Amid such varying conditions the sinking of a well in this region is very much of a lottery, even though it be true, as it seems to be, that the sand-gravel series beneath the clay is very extensive and everywhere water bearing.

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[a] Tarr, R. S., Artesian well sections at Ithaca, N. Y.: Jour. Geol., vol. 12, 1904, pp. 69-82.

The beds in which the wells are located are a part of the series of ice-front deposits associated with the stand of the glacier in this region. The source of the water is unquestionably the moraine series that occupies the bottom of the valley of the Cayuga Inlet, farther south. This being the case, the water supply must be great. That the water has long been underground is indicated by the analyses (Nos. 9 and 10 in the table)[a] and by its temperature, which in both August and December was 52° F. The Ithaca experiment will be watched with interest, for if only two-thirds of the estimated capacity of the wells is realized it will show a set of conditions in glacial deposits favoring, in a very limited region, the development of an extensive water supply.

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[a] The analyses of the water of the Illston well doubtless represent approximately the condition of the water in the neighboring wells of which analyses are not yet available.

WATER RESOURCES OF CENTRAL AND SOUTHWESTERN HIGHLANDS OF NEW JERSEY.

By Laurence La Forge.

INTRODUCTION.

Location.—This region, that part of the Highlands south of Andover and Pompton, about two-thirds of the Highland area of the State, includes portions of the Morristown, Lake Hopatcong, Hackettstown, Delaware Water Gap, Somerville, High Bridge, and Easton quadrangles, and comprises parts of Morris, Warren, Hunterdon, Somerset, and Sussex counties, covering an area of about 685 square miles. The limestone valleys lying within the Highlands are usually considered a part of the area and will be so regarded in this paper, together with the partially inclosed valleys, such as the Pohatcong and Pequest valleys, which extend between the Highland ridges for some distance, but open out into the Great Valley.

Population.—The population of the area is a little over 75,000. This includes the entire population of such places as Morristown, Boonton, and Bernardsville, which lie partly within the Highlands, but not the population of places like Clinton, Pompton, or Morris Plains, which are just outside the base of the Highlands, nor of places like Philipsburg and Belvidere, which are more properly comprised in the Kittatinny Valley. Of these 75,000 people, somewhat over two-thirds live in towns and villages, the strictly rural population averaging less than 35 per square mile. There are 20 towns and villages having 500 or more inhabitants, and about 50 more having from 100 to 500 inhabitants. The rate of increase for the area as a whole is about 1 per cent a year, but the actual increase is confined to the larger manufacturing towns in the valleys and to the parts of the southeastern border which are becoming popular suburbs of New York. In all of the upland portion and throughout the larger part of the valleys of the northern and central parts of the area the population is decreasing, there being a steady drift away from these localities. This, however, when the whole area is considered, is slightly more than offset by the influx from outside to the manufacturing towns and popular residence localities.

Industries.—The agricultural industry of the region is not so important as formerly, being now largely confined to the valleys and the peach-growing districts on the less rugged uplands of the southern portion. Lumbering is conducted on a small scale. Iron mining, formerly carried on in a small way at many places in the area, has become concentrated at a few important points and the mines elsewhere have been abandoned. There is a considerable and growing amount of manufacturing in the larger towns, mainly connected with the iron industry. The eastern slope of the Highlands, notably about Morristown and Bernardsville, has become a popular suburban region and is being rather thickly settled, while certain of the wilder and more beautiful of the upland districts, such as those on Mine and Schooley mountains and about Budd, Cranberry, and Hopatcong lakes, are favorite outing places, and of late years have a considerable summer population.

Climate, soil, etc.—The average temperature of the Highland region for the year is about 47°, the average for the winter being about 27°, and the ground and streams are usually frozen during the greater part of the winter. The average annual rainfall ranges from 38 to 48 inches in various parts of the region, and from 30 to 55 inches in different years. Usually there is somewhat more precipitation in summer than in winter. The average annual snowfall is about 5 feet, which is equivalent to about 6 inches of rain, so that about 12 to 15 per cent of the precipitation falls as snow.

North of the terminal moraine the soil is largely glacial material, entirely so along the moraine and in the filled valleys. South of the moraine the bulk of the soil in the valleys is also of glacial derivation, consisting of outwash plains in front of the moraine and of stream-washed drift lower down the valleys, but there are also areas of clay soil resulting from the weathering of the limestone and shale. On the uplands the soil is derived from the disintegration of the gneiss and is as a rule stony and not very fertile.

Forests cover a large proportion of the area, a proportion ranging from 90 per cent and more at the north and northeast to 30 per cent or less at the south and southeast. A greater percentage of the upland than of the valleys is forested, and a greater proportion of the glaciated area than of that lying outside the moraine. Except in parts of the limestone valleys and the plains of washed drift the soil is not very fertile, and the region, on this account and because of the ruggedness of a great part of it, is not well adapted for cultivation. The forest-covered area is increasing, as much of the land that was formerly cultivated is being abandoned.

TOPOGRAPHY.

The Highland region is a dissected plateau, lying about 500 feet above the lower country on either side, and bounded on the southeast by the Piedmont Plain and on the northwest by the Great Appalachian Valley, here known as the Kittatinny Valley. Northeastward the Highlands continue into New York, and to the southwest they extend past the Delaware for some distance into Pennsylvania.

The belt trends northeast to southwest and consists of several roughly parallel ridges and valleys which have nearly the same trend, but are not without local irregularities. A considerable portion of the original plateau surface remains as the summits of the broader ridges, reaching elevations of 1,200 to 1,300 feet in the northwestern part and declining gently both southeastward and southwestward. The highest point in the area, standing at an altitude of 1,333 feet above sea level, is in the town of Jefferson, northeast of Lake Hopatcong. The descent of about 500 feet from the plateau to the lower regions on each side is rather abrupt, and the longitudinal valleys within the highlands have been cut down about the same amount toward their lower ends.

DRAINAGE.

Lakes and ponds.—As there is abundant rainfall in the region and much comparatively level upland surface, with deep soil on most of the unglaciated portion, and natural storage basins everywhere in the glaciated portion, the entire area is well watered. On the slopes there are abundant springs, none very large, but many which never fail, and which can be depended on as sources of supply. Since much of the area is forested and other conditions are favorable to the absorption of water by the rocks, a large proportion of the rainfall becomes ground water, and a large part of the remainder is stored for a time in natural or artificial reservoirs.

Lakes and ponds are abundant in the glaciated area, the principal ones being enumerated in the following list. Of these several are entirely artificial, and nearly all the rest have been enlarged by raising the outlet level. Five are supply reservoirs for the Morris Canal and most of the others are or have been mill or forge ponds.

Principal lakes and ponds in central and southwestern highlands of New Jersey.

Name.	Area of water surface.	Area of drainage basin.	Elevation.	Drainage system.
	Acres.	*Square miles.*	*Feet.*	
Lake Hopatcong	2,443	25.4	928	Musconetcong.[a]
Budd Lake	475	4.5	933	Raritan.
Green Pond (Morris County)	460	1.7	1,045	Rockaway.
Stanhope reservoir	339	4.9	859	Musconetcong.
Split Rock Pond	315	5.3	815	Rockaway.
Denmark Pond	172	4.5	818	Do.
Cranberry Lake	154	3.0	771	Musconetcong.
Green Pond (Warren County)	117	5.2	399	Pequest.
Stickle Pond	110	1.7	783	Pequanac.
Forge Pond	96	10.1	775	Rockaway.
Shongum Pond	70	2.9	698	Do.
Waterloo Pond	68	(?)	640	Musconetcong.
Allamuchy Pond	56	1.8	775	Pequest.
Durham Pond	47	(?)	880	Rockaway.
Panther Pond	41	0.5	766	Pequest.
Bear ponds	38	0.6	977	Musconetcong.
Dixon Pond	35	3.5	560	Rockaway.
Wright Pond	31	3.4	743	Musconetcong.
Stag Pond	23	0.3	820	Do.

[a] Lake Hopatcong is naturally drained down Musconetcong River, but it supplies water for the summit level of the Morris Canal, so that a considerable part of its drainage actually passes down the Rockaway.

In addition to the lakes and ponds named above, there are about 100 small mill ponds and reservoirs, all artificial and mostly outside the moraine, and about 30 glacial kettle holes, which contain ponds each several acres in extent.

Swamps are numerous within or immediately in front of the glacial boundary, and largely increase the amount of storage on some of the streams. The largest, but also the lowest in elevation, are the Great Meadows of the Pequest and the long swamp on the upper course of the Black River. The rugged forest-covered area in Sussex and northern Morris counties contains scores of small mountain swamps, caused by glacial choking of old drainage channels, many of which lie at the very heads of the streams, at elevations of 1,000 feet or more.

Streams.—The region is drained partly by streams flowing along longitudinal valleys to the Delaware, and partly by streams flowing in both longitudinal and transverse valleys and reaching New York Bay. The principal rivers are the Pequest, Musconetcong, Raritan, and Passaic, the two last named being the largest and most important streams of the State. The entire region, except areas traversed by Pohatcong Creek and some minor streams that flow directly into the Delaware, is drained by these four rivers.

Pequest River is not properly a highland stream, its source and most of its headwaters being in the Kittatinny Valley, but in the lower part of its course it flows in a valley which separates Jenny Jump and Mohepinoke Mountains from the rest of the Highlands, and throughout its length it receives a part of the Highland drainage. At the head of Great Meadows, where it enters the Highlands, it is at an elevation of 532 feet. From here to Townsbury, where it escapes from the terminal moraine, it falls but 22 feet in 10 miles. This part of its course is through the bed of a temporary lake which was formed behind the moraine after the retreat of the ice, and until a few years ago, when extensive drainage works were completed, the meadows were an impassable morass. From Townsbury to Buttzville, where the river emerges again from the Highlands, it falls 130 feet in 6 miles and considerable water power is developed along this stretch.

Pohatcong Creek rises near Mount Bethel at an elevation of 1,000 feet and falls 400 feet in 5 miles to the valley at Karrville, along which it flows for 18 miles farther, reaching the Delaware at 135 feet elevation. Small water powers are developed at several points.

The ultimate source of the Musconetcong is in the town of Sparta, north of the area under consideration, at an elevation of 1,200 feet. It flows through Lake Hopatcong at 928 feet, Stanhope reservoir at 859 feet, and Waterloo Pond at 640 feet, emerging from the moraine at Hackettstown, 12 miles from its source, at 560 feet. From here to the Delaware, 31 miles below, it falls 430 feet. Lubber Run, its principal tributary, falls 450 feet in 10 miles from its source to where it joins the main stream near Waterloo Pond. Abundant water power is developed at a number of points on both streams.

Raritan River, the largest in the State, drains the central and southern parts of the area through three principal tributaries—the North and South branches and Black River—and empties into Raritan Bay, an arm of New York Bay. South Branch, the principal stream, rises in Budd Lake at 933 feet and falls 270 feet in 3 miles to Bartley, where it reaches the low-lying German Valley, along which it turns and runs 11 miles to Califon, falling 200 feet on the way. Here it plunges through a narrow gorge 6 miles long and emerges from the Highlands at High Bridge at an elevation of 220 feet. It carries a large volume of water and furnishes abundant power at many places. North Branch is not so large; its ultimate source is near Calais at an elevation of 1,000 feet. It falls 600 feet in the first 6 miles, but is here hardly more than a brook. From Ralston it cuts through Mine Mountain in a gorge of uncommonly picturesque beauty and emerges upon the lower plateau at only 180 feet. Though of small volume, it has a swift current and is utilized for power at several points. Black River, the third branch, rises in the moraine a little east of the southern end of Lake Hopatcong, crosses the Succasunna Plains, falling only 200 feet in 11 miles, and then drops 440 feet through a gorge 6 miles long in the Eastern Range, leaving the Highlands at Pottersville Falls at 240 feet.

The remainder of the area is drained by Passaic River, which empties into Newark Bay, another arm of New York Bay. The main stream is of little importance in its Highland portion. It falls only 289 feet in 5 miles from its source near Mendham to where it leaves the gorge at 280 feet elevation. The Whippany, another small branch, rises near Mount Freedom and falls 500 feet in 3 miles, but is here a mere brook. For the next 3 miles along Washington Valley to Morristown it is sluggish and flows through swamps most of the way. It leaves the Highlands at 310 feet and lower down becomes an important power stream. The Pequanac, another tributary of the Passaic lying altogether outside this area, drains a part of the northeastern corner.

The largest branch of the Passaic, and the most important in this area, is the Rockaway. This river rises high on the plateau to the north of the area, enters it in the Longwood Valley at about 750 feet, flows southwestward nearly to Wharton, where, at 660 feet, it turns eastward and cuts obliquely through the Eastern Range, emerging below Boonton at 240 feet. In the last 1½ miles of its gorge it falls 250 feet, furnishing one of the fine water powers of the State. It has a large flow and is an important stream both for power and for water supply.

GEOLOGY.

The rocks of the Highlands proper are granitic and hornblendic gneisses, hornblende and biotite-schists with lenses of magnetite, highly metamorphosed limestone and serpentine, and narrow bands of conglomerate and quartzite, also considerably metamorphosed. The origin of the gneisses and schists is uncertain, but a part at least were certainly igneous, and some of the remainder were probably of sedimentary origin. Throughout much of the area they are arranged in bands differing more or less in character, and the strike of these, as well as of the lenses of serpentine and iron ore and of the strips of sedimentary rocks, usually differs but little from the northeast-southwest trend of the ridges and valleys.

These rocks are for the most part very resistant to weathering, and give a bold, rugged character to the topography occupying the higher portions of the area, but the longitudinal valleys throughout most of their length are cut in much less resistant limestones and shales. These valley rocks and the strips of sediments on the ridges are of Cambrian, Ordovician, and Silurian age, while the gneisses and schists are pre-Cambrian. The age of the metamorphic white limestones is not yet settled. There are a few dikes of diabase and amphibolite in certain areas, but as a rule intrusive rocks are wanting.

The terminal moraine of the Wisconsin ice sheet crosses the area from Denville to Buttzville, and in the northern third of the region considerable areas of rock surface are found on the ridges, while the valleys are filled with sand and gravel to a depth of 200 feet in places. Glacial modifications of drainage are numerous, and in this part of the area a number of swamps drain in several directions.

WATER RESOURCES.

Importance of region.—This region, together with its northeastward extension into New York, is perhaps the most important in the United States from the point of view of water supply, because of its proximity to the great metropolitan area about New York City and its natural advantages as a collecting ground. The population of the portion of New Jersey east of the Highlands and north of Somerville and New Brunswick is over 1,100,000, and of that part of New York south of the Highlands and exclusive of Long Island, nearly 2,300,000. While the cities and towns of a considerable part of this area are still supplied with water from local sources, much of the region is rapidly becoming so thickly settled that in a short time it will be impracticable, except in a few limited cases, to depend longer on the local supply, both because of its inadequacy and of the increasing danger of pollution. The need of further supply for New York City is again becoming pressing, and because of the limited area of the Highlands within the State of New York, from which area the present supply is drawn, it may be necessary to go far up the Hudson or outside the State limits into Connecticut or New Jersey for additional water. Besides the population already mentioned, that of Brooklyn and Queens boroughs and Nassau County on Long Island amounts to 1,300,000. A considerable part, possibly all, of the supply for this territory can probably always be obtained from the deep water-bearing gravels of Long Island, but in the future legal complications may interfere with the obtainment from this source of the quantity needed, and at least a part of the supply may have to be procured from the mainland.

Natural advantages.—The Highlands lie in immediate proximity to this belt of dense population, forming its natural boundary on the northwest. The rainfall is abundant, the region is thinly settled and largely forested, and most of it is poorly adapted to the purposes of agriculture. There are many and capacious natural storage basins, and the whole district is so elevated that water may be delivered by gravity and under considerable head to the more densely peopled district. There is but little local contamination, and the region is so poorly adapted to ordinary uses that the sequestration of large parts of it as gathering and storage grounds for metropolitan water supplies is practicable at relatively small expense. These advantages have long been recognized, and the Highlands have repeatedly been pointed out as the future source of water supply for the cities of northern New Jersey, and the conservation of the Highland waters for that purpose has been often urged.

MINERAL SPRINGS.

There is but one mineral spring of note in the area, the formerly well-known Schooley Mountain Spring, located on the western slope of Schooley Mountain, about 2 miles south of Hackettstown. The result of an analysis of its water as given by Peale[a] is shown below:

Analysis of water of Schooley Mountain Spring.

	Parts per 1,000,000.
Calcium sulphate	28.7
Calcium carbonate	24.3
Magnesium carbonate	27.4
Iron carbonate	9.9
Sodium carbonate	9.9
Sodium chloride	7.4
Silica	12.7
Alumina	2.4
Ammonia	Trace.
Carbon dioxide (dissolved gas)	Undet.

This spring was formerly a popular resort; buildings were erected about it and the water was sold to visitors, but it is now abandoned and the water is no longer used.

WATER POWER.

The climatic and topographic conditions being favorable, the amount of available water power along the streams of the Highland region is considerable and it has been largely utilized. Of late years a notable change has been made in the use of this power, as the number of plants making use of water power has diminished, but the total amount utilized remains about the same. This is due to the fact that whereas there were formerly numerous small sawmills, flour mills, iron forges, and the like, each using a little power, many of these have been abandoned, but there are in place of them several large establishments which have been erected at favorable points and which use a considerable amount of power.

From a census of water powers of the State,[b] made by the geological survey of New Jersey in 1890, it appears that in the region discussed in this paper there was a total of about 11,500 horsepower used, 3,000 horsepower being used by mills on the Musconetcong and branches, 2,200 on Rockaway River and branches, and 4,500 on the two branches of the Raritan and their tributaries, the remainder being developed along various small streams, the Pequest standing at the head of these.

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[a] Peale, A. C., Mineral springs of the United States: Bull. U. S. Geol. Survey No. 32, p. 43.

[b] Vermeule, C. C., Final Rept. Geol. Survey New Jersey, vol. 3; appendix 1, water powers.

The largest development is in the gorge at Boonton, where there is a fall of 250 feet from the pond at Powerville to Old Boonton, with an estimated available horsepower of over 2,000, of which about 1,600 was utilized. At Highbridge, on the Raritan, about 1,200 horsepower is developed, and considerable amounts are used at Hughesville and Riegelsville, on the lower Musconetcong.

Though a much larger amount of power than has yet been utilized could be made available on these streams by proper conservation of the water in ponds, and the amount of manufacturing thus considerably increased, the fact must be recognized that the uses of water for power and for city supply conflict, and that one must necessarily largely preclude the other. If, as seems highly probable, the larger part of the stream and pond water in this region will before many years have passed be sequestrated for municipal supplies, the developed water powers of the Highland region are not likely to be further increased, but will probably be considerably diminished, at least on the Rockaway and Raritan and their branches.

THE MORRIS CANAL.

One of the largest users of water in the Highlands at the present time, and one which controls the water rights of several of the largest and most important storage reservoirs, is the Morris Canal, which traverses the region from Philipsburg to Boonton, passing through Washington and Hackettstown, crossing the low divide near Lake Hopatcong, thence, via Dover and Rockaway, issuing from the Highlands through the gorge at Boonton. It rises from 156 feet at Delaware River to 913 feet at the summit level, and then descends to 288 feet on the level below Boonton and to tide water at Jersey City. At Powerville and at Dover the boats are locked into and out of the Rockaway; therefore the whole flow of the stream is available at these points if needed for the purposes of the canal. Again, along the Musconetcong, from Stanhope to Saxton Falls, the waters of the canal and river mingle at several points.

Lake Hopatcong, Cranberry and Stanhope reservoirs, and Bear and Waterloo ponds are controlled by the canal corporation, and the water of these bodies is used for the canal supply. All except Lake Hopatcong supply the western slope of the canal, and the water thus reaches the Delaware. The Hopatcong feeder enters the canal at the summit level and furnishes the whole supply for the part of the eastern slope within the Highlands, except the water taken from Rockaway River. Nearly all the water drawn from Lake Hopatcong, therefore, passes down the eastern slope and reaches New York Bay, instead of following the original course of drainage from the lake to the Delaware.

Gagings have shown[a] that the canal appears to use very nearly the whole supply which can be obtained from the reservoirs in their present condition—in fact, the whole available supply in a dry season—as well as an unknown amount from the streams at the points where the waters are mingled; but by raising the dams and increasing the storage the reservoirs could be made to supply all the water needed by the canal in the driest seasons, as the rainfall on the catchment basin is ample when carried over by storage. It would seem, then, that the continued use of the canal would preclude the collecting of any surplus water from the upper Musconetcong and Lubber Run watersheds. Nearly all the water used by the canal, however, goes to make good the leakage, which is large on account of the hillside location of long stretches of the canal and the nature of the soil. From measurements made by Messrs. J. J. R. Croes and G. W. Howell this leakage has been estimated at 1.74 cubic feet per second per mile, and nearly the whole of this is returned to the streams, hence it again becomes available for storage in reservoirs on the lower courses of the streams and is not entirely lost as a source of municipal supply.

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[a] Vermeule, C. C., Final Rept. Geol. Survey New Jersey, vol. 3, Appendix 1, Water Power, p. 196.

The use of water for the ordinary purposes of the canal impairs to a very considerable extent its quality for domestic water supply, though, indeed, the water of the canal is used to some extent for that purpose in some of the towns along its course. Unfortunately, in one or two of the larger towns the canal receives the discharge of sewers, and throughout its length it is the receptacle of more or less refuse of all sorts, so that the use of its water for household purposes ought to be discontinued. The bulk of the leakage occurs by percolation through the soil, and hence the escaped water is to some extent purified by the filtration it undergoes in the process; but much of it escapes as overflow at the spillways, and the filtration of much of the rest is probably imperfect, as it is likely that long-continued leakage along certain lines has established little channels in the soil through which the water percolates with little or no filtration.

The water, then, of valley streams which derive a large part of their flow from the leakage from the canal is still of doubtful purity for domestic use, but, in view of the comparatively small pollution which the canal water must suffer and the large dilution which the escaped water undergoes by mingling with stream water derived from other sources, as well as the purification which would be brought about by its storage in large reservoirs on the lower courses of the streams, it is probable that the escaped water is not unfit, after such dilution and purification, to be stored for a metropolitan supply, especially if the reservoirs are large enough and the dilution is ample. It should be noted in this connection, however, that for some time there has been a movement to bring about the abandonment of the canal. Should this be accomplished, it would set free for other uses the large quantities of water at present required for the purposes of the canal, and would remove that particular source of pollution.

LOCAL WATER SUPPLIES.

Requirements.—There are about 20 towns and villages in or upon the immediate border of the part of the Highlands discussed in this paper that are large enough to need water systems, and 10 of them have such systems. With the exception of Morristown and Dover these places are all of less than 4,000 population, and the amount of water needed for their supply is comparatively small. The total population of those towns that have a water supply is about 32,000, and of those towns that are likely to need such a supply within the next ten years is about 8,000, so that the total number of people for whom local supplies of any magnitude must be reserved is not great.

Present sources.—As will be seen from the accompanying table, those towns that have public water-supply systems procure water from mountain springs, except Dover and Morristown, which procure a part of their supplies from drilled wells. It will also be noticed that municipal ownership is rare, only Dover, Hackettstown, and High Bridge owning their systems. Most of the systems are owned by companies, and in one or two cases the ownership is private and only part of the village is supplied by the system. The present sources of supply are ample for all present needs as well as for the near future, while in the cases of all but the largest towns it is probable that an ample supply for all future needs can always be obtained from sources now available.

The data incorporated in the table were procured by correspondence with officers of the various towns or of the water companies. No report was received from Gladstone, and the data given are derived from the best information available for that village.

List of municipal water systems.

Town.	Population in 1900.	Source of supply.	Kind of system.	Ownership.	Sufficiency of supply.	Quality.
Morristown	11,267	Springs and drilled wells	Gravity and pumping.	Private	Ample	Good.
Dover	5,936	do	do	Town	do	Do.
Boonton	3,901	Springs	Gravity	Company.	Not reported.	Not reported.
Washington	3,580	Springs and mountain stream.	do	do	Fair	Good.
Hackettstown	2,474	Mountain stream	do	Town	Abundant.	Very good.
High Bridge	1,377	Spring	do	do	Ample	Good.
Bernardsville	1,300±	Springs	do	Company.	do	Do.
Netcong	941	Brook	Not reported.	Private	Not reported.	Not reported.
Clinton	816	Springs	Gravity	do	Plenty	Good.
Gladstone	300±	Spring	do	do	(?)	Slightly hard.

The water, being taken directly from mountain springs or from drilled wells in favorable locations, is in all cases pure and wholesome, and there is slight danger of contamination. Morristown and Hackettstown report analyses that show water of exceptional purity. For all except the larger towns the springs furnish an ample supply, and hence drilled wells have been resorted to only where the population is so large that the supply from springs has been insufficient.

SURPLUS SUPPLIES.

Since the local population that requires a public water supply is not large, and since the supply is in all cases drawn from wells or springs and not from streams or large ponds, the effects which the needs of this population will have on the available supply for metropolitan purposes is negligible. On the other hand, since for most of those towns an ample supply can in the future be obtained from the present sources, their available supply is not likely to be affected injuriously by the utilization of the lake and stream water for the needs of the large cities. Many of the towns along the eastern bases of the Highlands seem destined to have a large increase of population in the future as metropolitan suburbs, and provision must be made for a greater supply for these, but they are fortunate in being located near small streams that flow from the hills, which are of sufficient volume to supply all their needs, but which run at too low an elevation or furnish too small a quantity of water to be used to advantage for the supply of cities at a distance. The growing manufacturing centers at Washington and about Dover and Wharton may also require larger amounts of water in the future than can be obtained from springs and drilled wells, but the needs of these places may be met without seriously diminishing the supply needed for city purposes. Washington especially, being located on Pohatcong Creek, which flows to the Delaware and is not so situated as to be used to advantage by the cities lying east of the Highlands, will probably always have a sufficient supply for local needs. Shongum Pond and Den Brook may easily be made available for a supply for Dover, and might well be reserved for that purpose.

Needs of the metropolitan area.—The need of water for the metropolitan area has already been briefly mentioned. Leaving out of consideration the 3,400,000 inhabitants of the New York part of the metropolitan district, there are over 1,100,000 in the New Jersey portion—about 60 per cent of the population of the State. The population of this congested area is increasing at the rate of 40 per cent in a decade, and should the increase continue at the same rate in fifty years the population of the New Jersey portion of the area alone will be a little less than 6,000,000. To keep pace with this increase there must necessarily be a gradual abandonment of the local sources of water supply and a turning to more distant regions where the supply will be both larger and in less danger of contamination. Newark has already taken this step, and Jersey City is at present providing for a supply from the Rockaway, at Old Boonton. Other large cities of the district must soon take similar measures.

It has long been known that there is no better region to which to turn for this purpose than the Highlands, where, not more than 25 miles from any of the cities of the district, a pure and abundant supply of water is available. Some of the cities of the metropolitan area are at present consuming about 95 gallons of water a day per capita, and though this amount seems excessive and implies waste of the water, still, to provide for possible contingencies, a source of supply which will be capable of furnishing 100 gallons a day per capita if necessary should be secured. On this basis, if the population of the New Jersey portion of the metropolitan district continues to increase at the present rate, in fifty years the inhabitants will require a supply of not less than 500,000,000 gallons a day.

Amount of supply.—According to the estimates of C. C. Vermeule,[a] the amount of water which can be collected on each of the watersheds of this region with proper storage is as follows:

Rockaway River (above Boonton), 78 million gallons a day; Raritan River (Highland branches), 92 millions; Musconetcong (above Hampton), 82 millions; a total of 252 million gallons a day. An equal or greater amount could be collected from the Ramapo, Wanaque, and Pequannock rivers in the northeastern Highlands, so that the amount of water in the Highlands which could be used for metropolitan supply is upwards of 500 million gallons a day, an amount very much in excess of the present needs of the New Jersey portion of the metropolitan area, and sufficient to meet the wants of this area for a long time. This estimate takes no account of the waters of the Highland portions of the Passaic and Whippany, which are small in amount and issue from the hills at so low an elevation as not to be advantageously used to supply places at a distance; nor of the Pohatcong and Pequest, which flow to the Delaware, and the waters of which could not be carried to the eastern side of the Highlands without considerable expense. Furthermore, these last streams drain limestone areas, and their waters are not so desirable for use as those of the more strictly Highland streams.

The water of the four important Highland streams which flow eastward, the Rockaway and Black rivers and the North and South branches of the Raritan, can be collected in storage basins at or near the points where they issue from the Highlands and delivered by gravity, making them easily available, and at relatively small expense.

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[a] Vermeule, C. C., Water supply: Geol. Survey of New Jersey, vol. 3, pp. 145, et seq. The writer desires here to acknowledge his indebtedness to this book, which is a mine of valuable information regarding the water resources of New Jersey and has been used freely in the preparation of this paper.

The North Branch of Rockaway Creek, in Hunterdon County, could also be used to advantage by the construction of a reservoir near Mountainville, and, it is estimated, would furnish more than 8 million gallons a day. The waters of the Musconetcong could be made available by the construction of a storage basin at Hampton and a tunnel through the hill to Glen Gardner, and thence to the South Branch of the Raritan; or a part of the Musconetcong could be utilized by the construction of a reservoir in the upper valley and a tunnel through Schooley Mountain. Furthermore, Lake Hopatcong, which drains naturally to the Musconetcong, lies so close to the divide that its waters could be diverted to the Rockaway and thus about 17 million gallons a day could be added to the flow of that stream.

There is a variation of over 50 per cent between the least and greatest rainfall in the Highland region, and thus a very great variation in the amount of water collectible in dry and wet years, but the estimates of Mr. Vermeule are conservative and are based on the computed flow for the driest eighteen consecutive months on record, and the amount of water given as available for the different streams may be relied upon under all conditions.

Character of the water.—The water of the Highlands in its natural state is of the very best quality, and a more satisfactory supply from this point of view could not be desired. Under present conditions, however, the water of the larger streams and of one or two of the lakes suffers contamination from several sources, and this must be guarded against before the water will be entirely fit for use. The Rockaway receives, above the reservoir now being constructed for the Jersey City supply, the sewage of Boonton, Rockaway, Dover, and Wharton, with an aggregate population of 14,000. This sewage, however, is all to be diverted before the reservoir is put into service, and the topography of the region is such that this can be done with little trouble. Hackettstown, with 2,500 inhabitants, is situated on the middle course of the Musconetcong, and there are increasing summer colonies on the shores of Hopatcong and Budd lakes, while there are still one or two important iron-mining localities in the region, besides a large blast furnace at Wharton. All these are to a considerable extent sources of contamination, but in nearly all cases the drainage can be conducted out to points below the sites where storage basins could be most advantageously constructed.

Though the village population is rather large in some other parts of the region, as along the stretch of German Valley, where the villages from Kenville to Califon have an aggregate population of over 3,000, it is as a whole not increasing, and the rural population nearly everywhere is decreasing, so that the danger of contamination other than from the large towns and manufacturing centers seems likely to decrease rather than increase in the future.

Availability.—Here, in immediate proximity to a large and rapidly growing urban district, for which there will be need in the not very distant future of an abundant water supply, is a region which is especially fitted by its natural advantages to be the gathering ground for that water supply—a very nearly ideal gathering ground. It seems certain, if the growth of the metropolitan population continues at its present rate, that in a few decades it will be necessary to utilize very nearly all the available water obtainable in the Highlands for the needs of that population and to conserve the supply by the construction of storage reservoirs. For this purpose it will therefore be necessary to set apart considerable portions of the region, both to provide room for the storage basins and to prevent contamination within their catchment areas.

This seems inevitable, and, like all work of the kind, it can be done at less expense and at greater advantage now than later, and, as a further motive for early action, it should be noted that the present need is great. When there are also taken into consideration the manifest adaptability of this region for use as a State park and the desirability of preserving its natural beauty for the enjoyment of the people of the densely settled area to the east, together with the fact that this use of the region would not conflict with its use as a source of water supply, the argument for the sequestration of a large part of the Highland area by State action, with the conservation of its natural beauty as well as its waters for the use of over one-half of the people of the State, becomes more potent. Indeed, it may well be a subject for interstate action, since, as has been shown, the needs of the population on the New York side of the Hudson are likely soon to be greater that can well be supplied from watersheds within the bounds of New York State, while since the advantages of the Highlands as a recreation ground would be as easily available to the people of New York as to those of New Jersey, the former State could well afford to share with the latter the expense of sequestration of the region, especially since a considerable part of the New York Highlands could advantageously be included within the area which it is desirable to reserve for this purpose.

WATER RESOURCES OF THE CHAMBERSBURG AND MERCERSBURG QUADRANGLES, PENNSYLVANIA.

By George W. Stose.

The Chambersburg and Mercersburg quadrangles are located in southern Pennsylvania, about midway between the eastern and western limits of the State, their southern boundaries lying within 2 miles of the Pennsylvania-Maryland line. They include a portion of the Cumberland Valley, extending from South Mountain at Waynesboro, Franklin County, to Tuscarora Mountain on the west, and a small portion of Fulton County about McConnellsburg.

The principal streams in this area are the Conococheague, flowing from South Mountain westward across the area; the West Branch of the Conococheague, flowing from north to south and joining the Conococheague at the southern boundary of the area; Licking Creek and Back Creek, tributaries of the Conococheague; and Little Antietam Creek, issuing from South Mountain, in the eastern portion of the area. All of these streams have a plentiful flow of water throughout the year. They are dammed at many places for water power to run grist, saw, and woolen mills. Many of the minor streams are similarly utilized on a smaller scale. At the mill above the village of Markes an electric plant has been erected, which supplies Mercersburg and some of the smaller neighboring towns with light. Electric railways are being constructed in the area, and the mountain streams, especially Buck Run at Cove Gap, are contemplated as a source of power. The mountain streams have not been utilized to great extent for this purpose, but they promise to be a fruitful source of power by reason of their constant supply of water, the feasibility of damming, and the large fall which may be obtained.

All the streams in the mountain valleys and ravines furnish good-sized flows of pure, limpid water. On reaching the open limestone valley the water rapidly sinks into the mountain wash and disappears, ultimately finding its way into subterranean fissures in the limestone. There are many large springs in the limestone area, but no system of underground channels has been observed. The water from these limestone springs is also pure and sparkling as it flows from its rock caverns, but this is due to its high content of lime carbonate, which is subsequently precipitated as mechanical sediment. On this account it is not so desirable for domestic uses as the pure mountain water, and most of the larger towns pipe their water from the mountains.

Chambersburg, the county seat of Franklin County and the railroad center of the area, obtains its water from Conococheague Creek, from which it is raised 100 feet to reservoirs on the shale hills opposite the town. This creek emerges from the mountains 12 miles east of Chambersburg, where it is fed by many mountain streams. It is in general a large stream, but at this distance from the mountains it is often muddy and at times low, and is subject to contamination by waste from small towns and mills along its course. The water is therefore not of the best quality. A purer and more desirable supply could be obtained from Rocky Spring or Falling Spring, about 4 miles distant, the waters of both of which, however, are hard; or, better still, from Crawford Springs, which issue from the sandstones of South Mountain, 7 miles east of the town.

Waynesboro obtains its water from a small mountain stream in South Mountain 4 miles to the east, where a receiving reservoir has been constructed 250 feet above the town. The distributing reservoir is located on a shale hill to the north of the town. Fayetteville, although it depends chiefly on well water, pipes part of its supply from springs in South Mountain.

The State Soldiers' Orphans' Industrial School at Scotland has a water system of its own, utilizing some small springs on the premises and pumping the water to an elevated tank. Greencastle takes its water from several limestone springs that supply a reservoir situated 2 miles east of the town and 150 feet above it.

Fort Loudon has incased a spring on the east side of Cove Mountain, 1 mile west of the town, and the water is made to flow continually through the old public pumps on the main street, from which the inhabitants help themselves. This supply is unusually pure and cool on account of its continual flow and because it does not stand in an open reservoir. A similar flowing public pump is located at Foltz, at which place the waters of Buck Run are taken where it issues from the mountains. A company has been formed to pipe this water from a point farther back in the mountains to the town of Mercersburg (4 miles southeastward), which at present has only private wells.

McConnellsburg, west of the mountains, is supplied from a spring and reservoir on the mountain slope 200 feet above the town and 1½ miles distant. The other smaller villages in the area depend on private wells and springs for their supply.

In South Mountain there are several noted springs. Mont Alto Park, formerly belonging to the Mont Alto Furnace Company, but recently purchased by the State as a timber reserve, is located in a gap through which flows a stream that is supplied by a number of fine springs, which issue from the sandstone. Pearl and Tarburner springs are the best known. The mountains at the gap have a dense growth of large pine and fir, preserved by the Mont Alto Company, and the park which that company established here, with its pure mountain stream and springs, and outlooks on the heights above, is one of the most attractive resorts in South Mountain. All that it lacks to make it complete is a hotel.

At Crawford Springs, in South Mountain, 2 miles north of Fayetteville, Doctor Crawford once conducted a health resort. A hotel was located here, and baths were built over the springs. The Tarburner Spring was, and is still, similarly utilized. Springs are plentiful in Tuscarora Mountain also, but none have been developed for special purposes.

There are several large limestone springs in the area, marked by beds of water cress and by stately weeping willows. At Falling Spring and Aqua, 3 miles east of Chambersburg, there are numerous large springs, which join to form a good-sized stream. These issue from sandy beds in the limestone series on the sides of an anticline.

Rocky Spring, 4 miles north of Chambersburg, flows from the limestone at a fault contact with overlying shales. This large spring is one of the chief sources of Back Creek.

Blue Spring, 3 miles southwest of Mercersburg, issues in a large pool from the center of a flat anticline in the limestone, but again flows through a cavern before it finally emerges to form one of the chief sources of Licking Creek.

Mount Holly Springs, about 25 miles northeast of this area, along South Mountain, is a very attractive summer resort. The springs issue from the sandstone cut by the gap, and a pretty park has been built around them. Two hotels located here entertain a large number of summer visitors. A paper mill in the gap uses the pure mountain water directly from the springs and makes a high grade of bond paper, which is used by the Government. Another paper mill uses the town water, which is piped from a reservoir at Cold Springs, 3 miles to the southwest. This is not so fresh nor so clear as the water at the upper mill, and consequently the paper is not of so high a grade.

WATER RESOURCES OF THE CURWENSVILLE, PATTON, EBENSBURG, AND BARNESBORO QUADRANGLES, PENNSYLVANIA.

By FREDERICK G. CLAPP.

These quadrangles are situated near the eastern edge of the bituminous coal field in the west-central part of Pennsylvania. The first three named cover a north-south belt lying mostly in Clearfield and Cambria counties, but include small portions of Bedford and Blair; the Barnesboro lies west of the Patton, in Cambria and Indiana counties. Within the area itself there are no large towns; but Clearfield, with 5,000; Altoona, with 29,000; and Johnstown, with 36,000 inhabitants, lie, respectively, 4, 5, and 10 miles outside. Throughout the region are scattered a number of flourishing mining and other towns having a population of less than 3,000, and some of the better parts of the basins support a scanty farming population. About one-half of it consists of extensive barren tracts, either forested or burnt over, which are very sparsely inhabited.

The Ebensburg quadrangle contains some of the highest land in the State, the anticline along the crest of Allegheny Mountain forming the water parting between the Conemaugh and Little Juniata rivers. A second belt of high land enters the area along the Viaduct and Laurel Hill anticlinal axes; a third, less continuous, along the Nolo axis, in the Barnesboro quadrangle; and a fourth, a broad, high wilderness along the Driftwood axis, cuts across the northwest corner of the Curwensville quadrangle. With a few exceptions the principal streams flow in a northeast course, following in a general way the anticlinal axes. The largest river is the West Branch of the Susquehanna, which rises on the west side of Laurel Hill near Carrolltown and flows 40 miles before finally leaving the area. Chest Creek, a tributary to the Susquehanna at Mahaffey, has a total length of 31 miles. Clearfield Creek, flowing northeastward from Cresson along the western slope of Allegheny Mountain, has 22 miles of its length within the area. Other less important streams are the Conemaugh River, Two Lick, Black Lick, Anderson, and Little Clearfield creeks. The grade of the streams is usually light, and none of them are used for power except locally. In a few instances, the most important of which are at Patton and Curwensville, the water supply for towns is taken from neighboring creeks.

With the exception of small tracts of Pottsville sandstone, and of an area of lower Carboniferous and Devonian rocks in the southeastern part of the Ebensburg quadrangle, the region is covered entirely by the Lower Productive and Lower Barren Coal Measures, and, as the dips are very gentle, rarely exceeding 200 feet in a mile, springs are numerous throughout, furnishing the farming population with abundant drinking water of excellent quality. Several of the smaller towns obtain their water supply from this source. The principal exceptions to the general abundance of springs are on the barren sandstone flats covering the crests of many of the ridges and in some of the shales of the barren measures, where they form hilltops along the Wilmore and Johnstown basins. The water of the region is nearly always soft.

At Cresson station is situated the Cresson Springs Hotel, now closed, but formerly a summer resort of the Pennsylvania Railroad, which made much of the water from a "magnesia spring" coming from a shale bed some distance above the Mahoning sandstone. A mile southeast of the town are an "iron spring" and a "sulphur spring," located at the horizon of the Upper Freeport coal. Several hotels at Cresson and Altoona are reported to serve water from these springs, and it is also sold extensively in Pittsburg. The following analyses of the waters were made by Prof. F. A. Genth:[a]

Analyses of water in springs near Cresson station, Pa.

[In parts per 1,000,000.]

	Iron spring.	Alum spring.	Magnesia spring.
Sulphate of ferric oxide	Trace.	571.0	....
Sulphate of alumina	27.4	362.6	....
Sulphate of ferrous oxide	401.5	278.0	....
Sulphate of magnesia	386.1	473.6	....
Sulphate of lime	836.5	687.4	1.9
Sulphate of lithia	Trace.	.8	....
Sulphate of soda	28.1	12.0	....
Sulphate of potash	5.5	7.3	....
Chloride of sodium	.7	.4	21.0

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[a] Second Geol. Survey Pennsylvania, Rept. HH, p. 36.

Analyses of water in springs near Cresson station, Pa.—Continued.

	Iron spring.	Alum spring.	Magnesia spring.
Bicarbonate of iron	86.1	64.1	0.3
Bicarbonate of manganese	Trace.	....	Trace.
Bicarbonate of lime	60.3	....	.4
Phosphate of lime	.5	Trace.	.1
Silicic acid	20.7	32.0	15.6
Chloride of magnesium	....	....	9.6
Chloride of calcium	....	....	22.3
Bicarbonate of magnesia	....	....	7.1
Bicarbonate of soda	....	....	24.4
Bicarbonate of potash	....	....	3.5
Alumina	....	....	.1
Nitrous acid	....	....	Trace.
Carbonic acid (free)	....	....	11.3
	1,853.4	2,489.2	117.6

The drinking and cooking supply of the towns is obtained from various sources, a tabulated list of which is given below. Several of these are worthy of especial note. Curwensville obtains its principal supply from mountain springs situated 2 to 3 miles from the town, which have been analyzed and found to be exceedingly pure. In the middle of the summer these springs sometimes run low, and at such times the water of Anderson Creek is used, being pumped to a system of sand beds through which it is filtered. Whenever a change is made to creek water the company gives notice to consumers that it should be filtered or boiled before using. The most extensive use of creek water is at Patton, where the water of Chest Creek is used almost entirely, being pumped by the Patton Water Company unto reservoirs. This water is of very good quality. In addition to the appended list Altoona and Holidaysburg must be mentioned, as they obtain their water supply principally from within the Patton and Ebensburg quadrangles. The former place uses water from Burgoons Gap Run, below Delaney; the latter from Blairs Gap Run. The Pennsylvania Railroad supply in the vicinity of Cresson comes from a reservoir in Bear Rock Run, several miles distant.

Sources of supply of the principal towns.

Name.	Population.	Source of supply.	Quality of water.
Gallitzin	2,700	Pumped to reservoir from mountain stream 1½ miles north of town.	Reported fairly good.
Patton[a]	2,600	Pumped to reservoirs from Chest Creek.	Good.
Curwensville	1,900	Mountain springs Anderson Creek when springs run low.	Excellent. Must be filtered.
Cresson	1,700	Reservoir on hillside east of town.	
Hastings	1,600	Reservoir in ravine above Stirling No. 8 mine.	
Ebensburg	1,600	Artesian wells	Good.
Spangler[a]	1,600	Reservoir in ravine below Benedict.	Contaminated by drainage.
Barnesboro[a]	1,500		
Lilly	1,300	Small stream 2 miles east of town fed by mountain springs.	Supposed to be good.
Coalport[a]	900	Wells	Good.
Portage	800		
Carrolltown	800	Pumped from spring	Reported to be best quality.
Mahaffey	700	Piped to town from wells and springs.	
Irvona	700	No waterworks; supply obtained from wells.	
Grampian	600	Two private water lines from springs within the borough limits supply about one-third of town; rest of supply from wells.	Wells are good; water from private lines has been questioned, as it is in danger of contamination.

[a] Discussed in the text.

The poorest source of supply is probably that of Barnesboro and Spangler. These two towns have granted a franchise to a private company by which they are furnished with water from a reservoir in the ravine southeast of Spangler. Above the reservoir has been built the mining town of Benedict, the drainage of which dangerously contaminates the Barnesboro and Spangler supply. Several alternative sources have been suggested, the most practicable plan proposed probably being to use the water from Lancashire No. 8 mine, which is supposed not to be seriously polluted, and which is now pumped to a private reservoir. The use of this water or that from some still less contaminated ravine in the vicinity might afford relief, but it is doubtful whether the improvement would be more than temporary. Barnesboro and Spangler, together with the neighboring towns of Moss Creek, Cymbria, Bakerton, Hastings, and Benedict, all within a radius of 3 miles, comprise a growing mining community which, if it increases in population at the present rate, will in a short time contaminate all the water in the vicinity. It is improbable that any of the ravines containing outcrops of workable coal can escape contamination within the next few years.

Conditions similar to those in the vicinity of Barnesboro exist on a smaller scale at many other mining towns, both within and without the area under consideration. While many of these towns now have satisfactory water supplies, a large number have not, and it seems probable that the question of water supply will soon become serious. Since only temporary relief can be afforded by change from one surface source to another, it will be necessary to prospect below ground.

Heretofore the abundance of good springs in the region has made it unnecessary to sink many wells, although shallow wells are frequent along the valleys of the larger streams and in most of the towns, and deep wells have been sunk at a number of places. The most abundant of these are in the vicinity of Ebensburg and Chest Springs. At Ebensburg they furnish the water supply of the town, which is consequently of the best quality. On the hills immediately east of Chest Springs a number of wells have been drilled in the barren measures and sometimes reach to depths exceeding 100 feet before striking water. Isolated wells were observed at farmhouses on the ridges southeast of Curwensville, south of Mahaffey, and in the vicinity of Marron. At a point directly south of Lumber City a tank has been erected on a hill to contain water for irrigating an orchard. This is the only case of irrigation known in the region. At the tanneries in Curwensville, on the flood plain, several wells have been drilled, which supply abundant water from horizons 100 to 200 feet below the top of the Pottsville formation. At the Westover tannery there is a well 182 feet in depth. The only flowing well observed was at Wilmore. This has a strong flow, due to a head of 1,000 feet, caused by the anticlinal structure of Allegheny Mountain on the east and indicates that if from any cause water should ever become scarce an abundant supply could probably be obtained by sinking artesian wells along the Wilmore basin. Similar conditions, but with a smaller head, must prevail in the other basins. It would seem, therefore, that the only true and permanent remedy for poor water supply in the coal-mining towns will be to drill artesian wells along the deeper basins. In view of the far-reaching importance of pure drinking water, it can not be urged too strongly that test wells be put down at well-chosen points in the several basins.[a] This is the only way to determine with absolute certainty whether or not such a supply is available.

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[a] Since this report was written the pure-water problem has been successfully solved by the borough of Coalport, which has had two wells drilled into the Pottsville sandstone. These wells are reported to find little water in the sandstone itself, but to obtain a good supply from the fire clay directly below the Brookville or "A" coal. The water has a very pleasing taste and exists in sufficient quantity to supply the entire town. A good head is obtained by pumping to a reservoir on the hill.

WATER RESOURCES OF THE ELDERS RIDGE QUADRANGLE, PENNSYLVANIA.

By Ralph W. Stone.

The Elders Ridge quadrangle is located in west central Pennsylvania, between the valleys of Cowanshannock Creek and Conemaugh River, and covers an area of about 225 square miles. The boundary line between Armstrong and Indiana counties extends from the northeast corner of the quadrangle to Kiskiminitas River, in the southwest corner.

The topography of the quadrangle is hilly. The extremes of altitude range from 825 feet on Kiskiminitas River, near Salina, to 1,625 feet, the elevation of the top of Watt Hill, the highest point in this vicinity. Although the difference in altitude between the highest and lowest points is therefore about 800 feet, the average distance between the valley bottoms and the uplands is not more than 300 feet. A few small areas, each comprising less than a square mile, are approximately level. These are the terrace and flood-plain deposits along the larger streams. Some of the ridges appear comparatively flat topped when viewed from an elevation. The valleys are narrow and, as a general rule, without notable flood plains.

The drainage of this quadrangle is westward into Allegheny River. The largest stream is Kiskiminitas River, which crosses the southwest corner for a few miles. It is shallow, has a number of rifts, and can not be navigated except by rowboats, and even by them only for short distances. The main tributary of the Kiskiminitas in this quadrangle is Blacklegs Creek, the largest stream in the southern half of this territory. It rises in the vicinity of Parkwood and West Lebanon and flows southwestward to its mouth at Saltsburg. This stream is so small that it can be forded at a number of places, and its grade is so gentle that a dam near its mouth backs the water up for a considerable distance.

Crooked Creek flows across the northern half of the quadrangle from east to west, and receives the waters of Plum Creek and Cherry Run. East of Girty the valley of Crooked Creek is comparatively broad, but from that point westward the stream flows through a deep and narrow gorge, with bluffs often 200 feet high. The stream can be forded at but few places in this quadrangle, and carries a sufficient volume of water, even during the low summer stages, to furnish power for a number of grist mills. Dams have been built across it at Cochran Mills, South Bend, and Idaho. It falls 130 feet from Shelocta to Cochran Mills, a distance of nearly 18 miles as the stream flows, and furnishes sufficient head for water power at frequent intervals. Cherry Run, a tributary to Crooked Creek at Cochran Mills, drains the northern portion of the quadrangle. At least one mill derives its power from this small stream. Plum Creek, formed by the junction of its north and south branches, joins Crooked Creek above Idaho and brings in a considerable amount of water. It drains the northeastern corner of the quadrangle and flows across a broad alluvial plain. Its grade is very gentle and it has not yet been utilized at any point for water power. All of the streams in this quadrangle have much steeper grades toward their sources, and in many places are doing rapid cutting in the neighborhood of the divides.

So much of the country has been cleared of timber that, although the rainfall is moderate, after heavy storms the streams rise suddenly and at that time carry enormous volumes of water. The excessive supply, however, runs off almost as quickly as it appears, and damage is done only to such property and crops as are located on the flood plains.

The largest settlement in the Elders Ridge quadrangle is Avonmore, on Kiskiminitas River, which, according to the census of 1900, has a population of 630. The water supply of this village is derived from wells sunk into the sands and gravels of the river terrace on which it is built. Wells dug but a few feet into this loose material obtain a sufficient supply of good water.

The next largest place is Elderton, with a population of 300. It is situated in the northern part of the quadrangle, on a small plateau, at an elevation of 250 feet above Plum Creek. The village water supply is obtained by private wells of the suction and chain type.

This quadrangle is distinctly a rural district, devoted to agriculture, and, as is usual in such cases, depends almost entirely on wells and springs for its water supply. On a few farms windmills are in use for elevating water to private tanks. Roadside springs with water troughs are common, and water can be obtained at almost any point by sinking wells a very short distance beneath the surface. The rocks that are commonly known as good water bearers are the Mahoning sandstone, which lies immediately above the Upper Freeport coal and outcrops over the greater part of this quadrangle, and the Pittsburg sandstone, which overlies the Pittsburg coal and is found in the southern portion of the quadrangle west of Blacklegs Creek.

WATER RESOURCES OF THE WAYNESBURG QUADRANGLE, PENNSYLVANIA.

By Ralph W. Stone.

The Waynesburg quadrangle is located in the southwestern corner of the State of Pennsylvania, in the eastern half of Greene County, its southern boundary being 2 miles north of the West Virginia State line and its western boundary about 15 miles east of the western line of the State. Its dimensions are about 13 by 17 miles, and it comprises about 229 square miles.

The topography of this quadrangle is uniformly hilly. The difference in elevation between the bottoms of the valleys and the crests of the ridges does not exceed 500 feet. The ridges in a general way trend northwest-southeast, but can not be said to have any conspicuous features. This part of Greene County is distinctly an agricultural district, and is reached by Monongahela River and by a narrow-gauge railroad from Washington County.

The drainage of the quadrangle is eastward to Monongahela River. The Monongahela itself crosses the northeast corner of the quadrangle for about 2 miles. Owing to slack-water conditions, this stream is navigable throughout the greater part of the year and affords an outlet for the products of the country about its headwaters at all times, except when it is choked with ice. Without its dams and locks the Monongahela would be little better than a broad creek. The principal tributaries of the river in this quadrangle are the north and south forks of Tenmile Creek, and Muddy, Whiteley, and Dunkard creeks. The north fork of Tenmile enters from Washington County and joins the south fork at the village of Clarksville, a short distance from the Monongahela. The south fork of Tenmile pursues the longest course of any stream in the quadrangle, having its rise in the west-central part of Greene County and extending entirely across this territory in a winding northeast direction. Muddy and Whiteley creeks have low grades in much of their courses. In fact, the streams in this quadrangle have no high grades, except near their headwaters. They are subject to flood and to seasons of slight flow, and in summer are likely to diminish to such an extent that the water stands along their courses in pools, with only a very small volume of running water. It seems that there is not sufficient supply for water power at any one point.

The village of Waynesburg is the largest settlement in the district and has a population of about 3,500. The next largest village is Jefferson, which has a population of 310, and there are a number of smaller hamlets. These villages are located for the most part on the stream courses, where travel is easier than along the uneven crests of the ridges.

Waynesburg derives its water from the south fork of Tenmile Creek, at the western end of the village. It is pumped to a reservoir on the hill north of the village at an elevation of 250 feet above the main street. As the creek carries considerable silt after every heavy rain, the supply is often muddy, although it passes through a sand filter before reaching the reservoir. For days at a time the water drawn from faucets is so heavily charged with sediment as to be almost useless. There seems, however, to be no other adequate supply immediately available. The proposition to drill deep wells has been considered but never tried. Many of the people in Waynesburg—in fact, most of them—use well water for drinking purposes. In most places a well sunk from 17 to 30 feet will reach bed rock and furnish a sufficient amount of fairly pure hard water. The system of waterworks at Waynesburg is the only one in the quadrangle.

The village of Jefferson is located on a terrace deposit of clays and gravels, and obtains its water supply from wells sunk from 20 to 60 feet through this material to bed rock. The supply is sufficient, and but few of the wells have been known to go dry, except during a protracted drought. The water is hard. In all of the other villages in the Waynesburg quadrangle the water supply is obtained from private wells, which are from 15 to 50 feet deep.

Springs are comparatively abundant in this country, and the water comes from various formations. The Upper Washington limestone is a frequent water producer. Springs from this stratum are numerous in Franklin and Washington townships. It is believed that the Waynesburg sandstone, which overlies the Waynesburg coal, and often has a thickness of 40 feet, is usually a water-bearing rock. Wells sunk into it yield an excellent quality of water, but care has to be taken not to penetrate to the coal.

The Waynesburg Cold Storage Company drilled an 8-inch well 134 feet deep at its plant in the village in March, 1901. This well struck water in the Waynesburg sandstone and yields a supply which the pump has never been able to exhaust. Although the pump raises 75 barrels an hour, day and night, there is always about 90 feet of water in the hole. The water is soft and is used for the ice plant.

WATER RESOURCES OF THE ACCIDENT AND GRANTSVILLE QUADRANGLES, MARYLAND.

By G. C. Martin.

INTRODUCTION.

Geography.—The Accident and Grantsville quadrangles are located in the "Handle" at the extreme western extension of Maryland. A strip about 2 miles wide, belonging to Pennsylvania, is included in the northern portion of each quadrangle, while a smaller and narrower strip of territory belonging to West Virginia is included in the western portion of the Accident quadrangle. Of the territory in Maryland all but a small area in the southeastern corner of the Grantsville quadrangle lies in Garrett County. Each quadrangle measures approximately 17¼ miles from north to south, 13¼ miles from east to west, and contains about 235 square miles. Friendsville, Md., in the Accident quadrangle, and Elklick, Pa., and Barton, Md., in the Grantsville, are the largest villages.

Relief.—The topography of the Accident quadrangle is mainly that of a plateau which has been deeply cut by streams. The surface of the upland lies in general between 2,500 and 3,000 feet, the highest parts being in the southern and eastern portions. There are no well-defined ridges rising noticeably above the general level of the uplands. The valleys, especially along the main drainage lines, are of the nature of canyons, whose bottoms are frequently from 500 to 1,000 feet below the plateau. In the Grantsville area there are three ridges rising nearly or quite to 3,000 feet, crossing the quadrangle with a northeast-southwest trend, between which plateaus, similar to that of the Accident quadrangle, are developed at an altitude of, between, 2,500 to 2,800 feet.

Drainage.—The drainage of the Accident quadrange is northward by the Youghiogheny to the Monongahela. In the Grantsville area the drainage is in part north by Castleman River to the Youghiogheny in Pennsylvania, and in part southward by Savage River to the Potomac.

WATER RESOURCES.

STREAM SUPPLIES.

Youghiogheny River.—The Youghiogheny and its tributaries drain almost the entire area of the Accident quadrangle. It is a large, pure stream whose capacity is far in excess of any probable demand. The only contamination of the main stream comes from the villages of Sang Run, Krug, Friendsville, and Selbysport, and from a few sawmills. The tributaries are all very pure.

Castleman River.—This stream drains the northwest half of the Grantsville quadrangle. It is a large, uncontaminated stream, but there is no demand for its waters in the agricultural region through which it flows in this quadrangle.

Savage River.—This stream drains the central part of the Grantsville quadrangle. It is a large, pure stream and furnishes the water supply for the towns of Piedmont, W. Va., and Westernport, Md.

Georges Creek.—This stream drains the southeast corner of the Grantsville quadrangle. The main stream and the lower courses of its tributaries are so polluted by sewage and mine water as to be totally unfit for any purpose. The headwaters of the tributaries are pure and would furnish good supplies of pure water for the many mining villages in the Georges Creek valley which are annually ravaged by typhoid fever.

SPRING WATER.

There are a great many large, pure springs along the belts of outcrop of the Greenbrier limestone. These belts extend (1) along the western foot of Big Savage Mountain; (2) along the eastern front of Meadow Mountain; (3) along the western front of Negro Mountain; (4) along the eastern front of Winding Ridge; (5) through the valleys of Deep Creek and Marsh Run from Thayerville to McHenry, thence westward to Sang Run and along Youghiogheny River for a distance of 2 miles north and south of Sang Run; and (6) along the northern and eastern edge of the Cranesville valley.

These springs are similar both in geologic relations and in the properties of their water to the group of springs from which the celebrated Deer Park spring water is obtained. The Deer Park springs are about 6 miles south of the southern limits of this folio, and are situated along the direct continuation of the line of springs at the western foot of Big Savage Mountain.

ARTESIAN WATER.

The possibility of obtaining artesian water has never been properly tested in this region. It is, however, probable that the synclines that underlie the valleys of Georges Creek, Castleman River, and Youghiogheny River are artesian basins, and would yield plenty of good artesian water from various horizons.

Several bore holes made in the coal-bearing portions of the synclines have yielded flows of water. This water came from the Coal Measures, and was therefore strongly impregnated with sulphur and iron. It is probable that deeper holes would yield better water from the purer porous sandstones which underlie the Coal Measures. There is, however, no present demand in the region for artesian wells, for the numerous pure streams and springs yield a supply of water that is sufficient for all needs.

WATER RESOURCES OF THE FROSTBURG AND FLINTSTONE QUADRANGLES, MARYLAND AND WEST VIRGINIA.

By G. C. Martin.

INTRODUCTION.

Geography.—These quadrangles are mostly in western Maryland, lying just east of the Grantsville quadrangle. Like the latter they cover a narrow strip of Pennsylvania along their northern borders, and include on the south a considerable area lying south of Potomac River and belonging to West Virginia. The portion in Maryland, except a small area in the northeastern part in Garrett County, falls in Allegany County. The West Virginia area is divided between Mineral County on the west and Hampshire County on the east. Cumberland and Frostburg, Md., are in the Frostburg quadrangle, but there are no large towns in the West Virginia portion of the area or in that part of Maryland that is included in the Flintstone quadrangle.

Relief.—The southwestern half of the Frostburg and nearly all of the Flintstone quadrangle is crossed at intervals of a few miles by ridges varying in altitude from 3,000 feet on the west to 1,500 feet or less on the east. Between these ridges, plateaus having altitudes varying from about 2,700 feet on the west to 900 feet on the east are developed. The plateaus, however, exhibit very little of their original level surface, being cut by numerous streams to depths of many hundred feet. The ridges are due to upturned hard rocks of Silurian, Devonian, and Carboniferous age, while the plateaus are composed mainly of Devonian shales and softer coal-bearing rocks of the Carboniferous.

Drainage.—The quadrangles are drained by the Potomac River, which enters the Frostburg area at its southern boundary, flows northeastward to Cumberland, and thence southeastward across the Flintstone area. The minor streams follow in general the trend of the ridges, those of the north flowing southwestward to the Potomac and those on the south northeastward to the same river.

WATER RESOURCES.

STREAM SUPPLIES.

North Branch of Potomac River.—The North Branch of the Potomac flows through the southern part of this area for a distance of 38 miles. It furnishes the public water supply for the city of Cumberland. The quantity of water is far in excess of the amount needed, but the quality is extremely bad. The water is, in fact, so polluted that it is entirely unsuitable for domestic or industrial use. The polluting matter consists of the refuse from a number of sawmills and tanneries, the drainage from a large number of coal mines, the chemicals from paper mills, dye works, woolen mills, and gas plants, and the sewage of Piedmont, Westernport, Keyser, Cumberland, and other towns. There is great need of some purer supply.

South Branch of Potomac River.—The South Branch of the Potomac is a large stream, which flows through this area for a distance of about 6 miles. It contains at all seasons a large amount of pure water. It is not used at present, and there is not likely to be any future demand for it. It is, however, very important, as it serves to dilute the impurity of the main stream of the Potomac, and thus improves the quality of the water supply of the city of Washington.

Georges Creek, Braddock Run, and Jennings Run.—These streams flow through the thickly populated mining regions in the western part of this area, and are so badly polluted by sewage and mine water as to be entirely worthless.

Smaller streams.—The headwater streams of the entire region, situated as they are largely in forested areas, are unpolluted and would furnish pure water supplies for the smaller towns. Evitts Creek, Patterson Creek, and Town Creek are the largest of the unpolluted streams, and all contain pure water for the entire length. Their water is not used at present.

SPRING WATER.

The largest springs in this region are on the belts of outcrop of the limestone formations. The lines of upper contacts of the Greenbrier limestone and the Helderberg limestone are marked by a great many springs of large, constant flow and great purity. One of these springs, at the contact of the Mauch Chunk shales and the Greenbrier limestone, at the western foot of Big Savage Mountain, furnishes a large part of the water supply of the town of Frostburg. This supply could be greatly increased by the development of other springs in neighboring localities. The town of Lonaconing, which is at present very poorly supplied with contaminated water, could get a similar supply on the western slope of Big Savage Mountain. The celebrated Deer Park spring water comes from a series of large springs not many miles southwest of this region in this same belt of outcrop of the Greenbrier limestone. A series of similar springs might be developed along the eastern part of the Dans-Piney-Little Allegheny Mountain range which would furnish a partial or even a complete supply of pure water for the city of Cumberland.

The line of contact between the Oriskany sandstone and Helderberg limestone and a large part of the areas of those formations contain a great many large springs which are important for local rural use.

ARTESIAN WATER.

Part of the water supply for the town of Frostburg is obtained from an artesian well 1½ miles west of that town, on the eastern slope of Big Savage Mountain. Water is said to have been found in sandstones of Carboniferous age at depths of 81, 182, 527, and 1,200 feet. The amount of water procured from the various horizons is not known; nor is it certain whether the water is derived from contaminated horizons near the surface or from deeper pure sources. If this well reached the Mauch Chunk-Greenbrier horizon and the shallower water were cased off an ample pure supply would result. There is an area of about 90 square miles in the northwest central part of the Frostburg quadrangle where, in the Georges Creek syncline, this Mauch Chunk-Greenbrier water horizon could be struck at depths of from 1,000 to 2,400 feet. The water will not rise anywhere in these wells above an elevation of 2,700 feet above sea level, and is probably drained out of the syncline in the vicinity of Braddock Run and Jennings Run to the level of 1,000 feet.

It is highly probable that the Oriskany and Tuscarora sandstones contain artesian water in their synclinal areas. There are areas to the north, northeast, and south of Cumberland where artesian wells, if properly located with regard to the local details of structure, would be almost certain to strike pure flowing water in the Oriskany and Tuscarora sandstones. Similar conditions exist over a large proportion of the Flintstone quadrangle, but except in the vicinity of Cumberland there is no demand for artesian water.

WATER RESOURCES OF COWEE AND PISGAH QUADRANGLES, NORTH CAROLINA.

By Hoyt S. Gale.

The Cowee and Pisgah quadrangles are in western North Carolina, their southernmost limits overlapping into South Carolina. They include parts of Macon, Jackson, Swain, Haywood, Transylvania, Buncombe, and Henderson counties in North Carolina. Their total area is about 1,950 square miles.

Geographically these quadrangles are situated in the heart of the southern Appalachian Mountains, covering an area of comparatively high and roughly dissected country. The headwater valleys of French Broad River, in the Pisgah quadrangle, and of Little Tennessee River, in the Cowee quadrangle, include the greater part of the open country they contain. The smoothly graded débris slopes of these and some other valley bottoms are in strong contrast with the sharp dissection of the territory in general. However, the area contains numerous remnants of old plateaus, recording several distinct periods of ancient peneplanation, and many examples of the original mature topography, as yet untouched by readjusting drainage, are found high up about the uppermost headwaters. Still above these plateau levels rise many residual peaks.

Drainage.—The larger part of the drainage belongs to the Mississippi River system. The Blue Ridge, the main divide between the Mississippi and the Atlantic waters, passes through the southern halves of the two quadrangles. Most of the streams south of this divide have worked their grades back to steep slopes, often escarpments, at their very heads. The Mississippi drainage north of the divide has, however, been less active in its channel cutting, being held up by greater difficulties in its paths and the longer route traversed to reach the sea level. Most of the remnants of old land topographies spoken of above are thus found on the Mississippi side of the Blue Ridge. Subsequent incision of these stream channels has not yet receded upstream far enough to affect grades at the headwaters.

The Cullasaja River is a good example of the streams on the Mississippi side of the Blue Ridge. Heading on the slopes of the residual peaks in the vicinity of Highlands, and also on the Highlands plateau, of about 3,800 feet elevation, it collects its waters from a drainage basin of smooth, well-rounded slopes. About a mile below Highlands it comes to the edge of this plateau and begins to drop off in cascades and falls, and its valley becomes steep sided and deep. The immediate locations of the falls are determined by the harder ledges of rock. In most cases here, as elsewhere in this region, these ledges are granite. In the next 6 miles the river drops 1,200 feet, an average grade of 200 feet in a mile. For the remainder of its course to Franklin its grade again flattens out. Along this stretch is the plateau of Little Tennessee River. From Rabun Gap, the main head of the Little Tennessee, to Franklin this river falls about 100 feet in 25 miles, or 4 feet to the mile. Below Franklin the Little Tennessee comes to the edge of this lower plateau and falls off more rapidly again.

French Broad River is in character very similar to the Little Tennessee. Along both rivers the lower plateaus are at an elevation of about 2,100 feet above sea level, and into them both streams have slightly incised their channels. The French Broad runs a course of about 45 miles from its main forks near Eastatoe Ford to the point where it leaves the Pisgah quadrangle. In this distance it falls from 2,180 feet to 2,000 feet above sea level—180 feet in 45 miles, or 4 feet in a mile. Streams so well graded are very exceptional in this region.

The west fork of Tuckaseegee River gathers into a stream of considerable size the waters of an upper plateau level of about 3,600 feet. Just below Glenville, in Jackson County, it comes to the plateau edge and drops 900 feet in 6 miles, or 150 feet to the mile. The East Fork similarly drops over 100 feet a mile for more than 10 miles.

The heaviest grades are south of the Blue Ridge. The descent is here concentrated into one steep slope from the Blue Ridge plateau down to the Piedmont Plateau. The intermediate levels that occur on the Mississippi streams do not occur here, so that the Blue Ridge is characteristically an escarpment overlooking the Piedmont Plateau. Cæsars Head is a feature of this escarpment. Ten miles west of Cæsars Head the Blue Ridge and the escarpment diverge, and an upper plateau intervenes between the main divide and the fall line of the streams. This plateau extends about 20 miles westward, as far as Whiteside Mountain. Streams heading within this belt, therefore, have flat headwater grades similar to those of Cullasaja River in the Mississippi drainage. However, the drop from the Blue Ridge plateau to the Piedmont Plateau is far greater than any that occurs on the Mississippi side of the divide. For example, the Toxaway River is 3,000 feet at Lake Toxaway, and in 5 miles it falls to 1,300 feet, or at the rate of 340 feet in a mile. It would seem that these streams offer much available power, but the falls are almost always difficult of access and most of them are distant from present lines of transportation.

Springs.—This is on the whole a region sparsely settled and little developed commercially or industrially, and little or nothing is known concerning the underground waters except as they issue in springs, or perhaps through the few existing wells. The country is abundantly supplied with springs, except along the gravel and bowlder deposits, which form the valley bottoms of the larger streams. The water is for the most part very pure. The rocks are typically siliceous or micaceous, containing little readily soluble material either in themselves or in their soils. The soils are loose and coarse, usually sandy rather than clayey, and do not afford much material that will stay in suspension in the water. However, mineralized waters do occur in numerous instances. These can be separated into at least two classes. Besides the granites and micaceous gneisses, a more basic rock, containing much hornblende and other iron minerals, traverses the region in long, narrow bands. Springs issuing along these bands are frequently heavily charged with iron. Their occurrence is rendered noticeable by the deposits of iron hydrates that accumulate about them. A spring that forms an excellent example of this class issue directly from a narrow outcrop of hornblende-gneiss just below the dam at Fairfield Lake, in Jackson County.

Another type of mineralization of spring waters has been noted where formation contacts, and especially zones of faulting, show a development of pyrite, with perhaps other minerals. Weathering of these to a soluble form stains the rocks with copperas and impregnates the water that flows through them. Sulphur and iron waters observed at a number of localities undoubtedly obtain their mineral content in this way. The most accessible and best known sulphur and iron water occurs at Waynesville, at the "Haywood White Sulphur Springs," but the writer is not prepared to say how it originates.

In considering the underground waters it is necessary to distinguish at least three definite types of topography and surface drainage which are conspicuous in this region. The thinly covered ledges of the residual peaks that stand above the old plateau levels shed water rapidly from their steep slopes. Flow within these massive rocks must be slight, except through cracks and fissures. On the plateau levels, however, prolonged weathering has produced a heavy cover of soil which must be comparatively porous. This is well supplied with water from the residuals, and on the other hand well supplied with outlet drains at the plateau edges, and a strong and constant underground flow must result within this cover. In the stream bottoms, at lower levels, are graded plains of wash débris, from which the water does not often come to the surface to form springs. Here the water supply, if not taken from the stream itself, must be drawn from wells or piped from neighboring hillsides. As the larger towns are usually situated in the open valley lands they are least easily supplied with pure water. All of the county seats within the area are so situated.

WATER RESOURCES OF THE MIDDLESBORO-HARLAN REGION OF SOUTHEASTERN KENTUCKY.

By GEORGE H. ASHLEY.

This area, which takes its name from the towns of Middlesboro and Harlan, is a belt of country occupying the region between Pine Mountain on the north and Cumberland Mountain on the south, and is located in Bell and Harlan counties, in southeastern Kentucky. It extends from the headwaters of Yellow Creek, near the Kentucky-Tennessee line, in a course about N. 60° E. to Big Black Mountain, a distance of about 60 miles. At its western end the belt is about 10 miles wide, at the eastern end about 15 miles wide, and its area about 750 square miles.

The topography is that of a basin bounded on the north and south by two high mountain ridges and limited on the east and west by the divides at the heads of the streams draining toward the middle of the basin and passing out by way of the Cumberland River through Pine Mountain at Pineville Gap. The region between the ridges has now been cut down by the rivers until only sharp ridges remain. These commonly vary from 2,500 to 3,400 feet in altitude. The streams are generally from 500 to 2,000 feet below the crest, the Cumberland River having an altitude of 980 feet where it leaves the basin. The slopes of the hillsides are nearly all steep, the only flat lands being narrow belts along the streams. The hills throughout the basin are generally forested.

Geologically the area is a synclinal basin, the axis of which lies to the north of the center, or nearer to Pine Mountain. In the center of the basin the dips are slight, but run up to nearly or quite vertical on the flanks of the bounding ridges. The rocks consist of alternating beds of sandstone, shale, and coal, the sandstones predominating.

Many cabins are scattered over the slopes and crests and in the ravines throughout the hilly region. In fact, the majority of the inhabitants are located among the hills, though the prosperous habitations are nearly all in the towns or along the river bottoms.

Along the bottoms water is obtained either from shallow wells in the river gravels or from near-by springs. In the hilly region springs are especially abundant and constitute the chief source of supply, even up to the very crests, although a few shallow wells have been dug on the hilltops. In times of prolonged drought the springs occasionally fail, and recourse is had to streams, which, however, are sometimes so low that water appears only in isolated pools. The waters of the springs and wells are noncalcareous and are of good quality.

The town of Middlesboro obtains water from Little Yellow Creek, a stream that flows along the foot of Cumberland Mountain and is fed from large springs from sandstone. The water is pumped from an artificial lake made by a concrete dam across the creek to a reservoir on a near-by hilltop. The pumping station is a mile from the center of the town. A large spring, which formerly came out a little below the summit of Cumberland Gap, was diverted by the building of the railroad tunnel and is now piped to town for the use of the local tannery. A number of deep wells have been bored at Middlesboro for oil, but, though obtaining no oil, at least one of them—that at the mouth of Bennett's Fork—gives an abundant flow of water from the Lee conglomerate. One well is 750 feet deep. Similar artesian water might be found elsewhere, but no other wells have yet been drilled.

Pineville is supplied from a small tributary of Hagan Mill Branch of Cumberland River. It is a small stream fed by springs on the south side of Pine Mountain, 1½ miles east of the gap. The pumping station is located on the Cumberland River.

Water power on a very small scale is obtained at a number of places on Cumberland River and on its forks and branches. At only two points is there promise of considerable power, one of which is on Shillaly Creek. This stream rises on a broad plateau between Cumberland and Brushy Mountain, and attains a considerable volume before it descends into the deeper valley. Martins Fork of Cumberland River heads near Shillaly Creek and descends in a similar but more gradual manner, and with somewhat larger volume.

SUMMARY OF THE WATER SUPPLY OF THE OZARK REGION IN NORTHERN ARKANSAS.

By George I. Adams.

During the progress of geological work in the Ozark region of northern Arkansas considerable data has been collected in regard to the water resources. This paper is intended as an outline of the conditions of occurrence of the springs, which are numerous and important. They are in many cases the heads of streams, with which the area is well supplied.

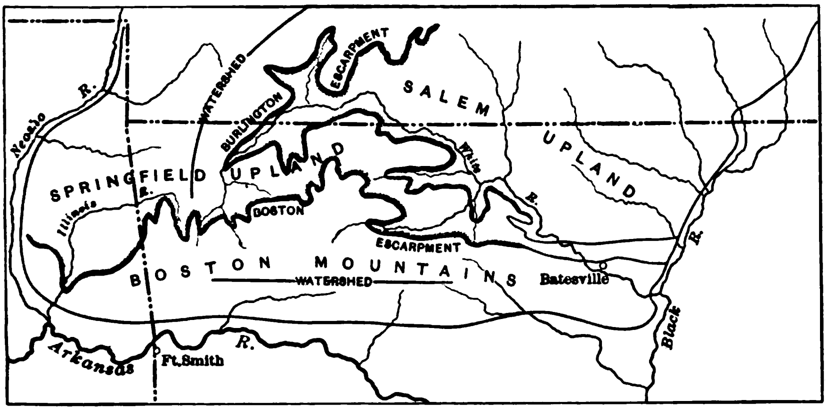

FIG. 32.—Sketch map of Ozark region in northern Arkansas.

The accompanying sketch map of a portion of the State shows the location and extent of the Ozark region. Observations have been largely confined to the western part of the area, but some of the springs in the eastern part have been noted, so that the geologic relations of the ground waters as outlined is thought to be consistent for the whole.

THE OZARK REGION AND ITS DIVISIONS.

The Ozark region in Arkansas includes two distinct types of country, the characters of which are determined by the structure and extent of the rock formations. The southern of these is the Boston Mountains, a dissected highland which extends from the vicinity of Batesville westward to the Indian Territory line. To the south it blends with the Arkansas Valley region. Its northern border is outlined by the Boston escarpment, which is very irregular, being cut by numerous stream valleys, between which are irregular peninsula-like promontories,

North of the Boston Mountains and at a lower level is the more even country that forms a part of the Ozark Plateau, which extends northward into Missouri. The surface features are closely related to the nearly horizontal rock formations. The rocks which outcrop in this area belong principally to two classes. They may be spoken of as the Mississippian limestone and the Ordovician dolomites. The Mississippian limestones are higher geologically and the area in which they outcrop is known as the Springfield upland. The area of the Ordovician dolomites is nearly coextensive with the Salem upland. These two divisions of the plateau are separated by a more or less distinct escarpment, known as the Burlington escarpment, which has a height of approximately 300 feet.

When viewed in a broad way the higher portions of the Springfield and Salem uplands are seen to fall in a slightly warped plain, which is dissected by the streams. The drainage of the western portion of the Ozark region in Arkansas is tributary to Illinois and Elk rivers, which find their way around the western end of the Boston Mountains into Grand River and eventually into the Arkansas. The remaining streams that head in the region are tributary to White River, which flows in an irregular course northward and then southeastward around the eastern end of the Boston Mountains. In the eastern portion of the Salem upland there are a number of streams which enter the State from Missouri. Some of these are tributary to White River within the Ozark region, while others enter Black River, which flows along the eastern border. The larger creeks, and especially the rivers, are perennial. The minor ones flow during most of the year, but during the drier seasons the water in them stands in pools or has a decreased flow, which is contributed by springs. The fact that the country is well watered is largely due to the nature of certain rock formations which hold a large content of water.

SPRINGS OF THE OZARK REGION.

The horizons of the springs are in large measure determined by certain formations which afford easy channels for the underground water, and by others which are impervious and guide the flow along the dip of the rocks to their outcrops. The following classification of the springs of the region is tentative only; further observations and more detailed study will probably enable a classification to be proposed which will more fully cover the conditions existing.

SPRINGS RELATED TO THE LIMESTONES IN THE BOSTON ESCARPMENT.

The rocks that outcrop in the Boston Mountains are principally sandstones and shales. There are, however, two limestone formations which, although usually but from 5 feet to 50 feet thick, are persistent.

The lower is known as the Pitkin limestone and the upper as the Brentwood. The effect of these formations on the topography, as the result of their manner of weathering, is to produce benches. Their outcrops, although often concealed, are frequently seen as conspicuous ledges. The ground water finds an easy path along the bedding planes and joints of these rocks, and because of slight undulations of the formation it converges at certain points and issues as springs. The occurrence of these springs at the headwaters of Illinois River in the vicinity of Prairie Grove, and at many other localities, influenced the early settlers in their selection of sites for homes. A spring of this type is seldom found which is not the site of a settlement, and in some cases they have determined the location of towns.

SPRINGS RELATED TO THE BOONE LIMESTONE AND CHERT.

The principal formation in the Springfield upland is the Boone limestone and chert. Circulating water finds easy channels along its bedding planes and joints, and, as is often the case in such rocks, numerous solution channels, and occasionally caves and sinks, have been formed in it. A large amount of the underground water in the Boone chert is contributed to the streams without appearing as springs. In some places, however, it issues at the heads of valleys or at levels above streams, and forms important springs. A few of the springs are so large that their waters have been dammed or conducted by means of flumes to furnish power for small mills. At many towns they are the source of water supply, and in some instances the locality is utilized as a summer resort, as at Monte Ne, for example.

SPRINGS RELATED TO THE SHALE BED AT THE BASE OF THE BOONE LIMESTONE.

In the western part of the Ozark Plateau a bed of shale ranging from a few feet up to 50 feet in thickness lies underneath the Boone formation. The influence of this impervious bed upon the circulation of the ground water is to carry it along its upper surface with the dip to the outcrop. Many springs issue at the base of the Boone limestone, just above the shale. The best known is Eureka Spring, which has become famed as a health resort. While many of the springs occurring at this horizon do not carry a large volume of water, they are of considerable importance as a source of domestic supply to individual households or neighborhoods.

SPRINGS RELATED TO THE SANDSTONE AT THE TOP OF THE YELLVILLE DOLOMITE.

Descending in the geologic section the next important formation as a source of springs is this sandstone. It is a loosely cemented sandstone, and the waters which issue from it are "softer" than those previously mentioned—that is, they carry but little lime. The water issuing from the sandstone does not usually afford a large supply, but because of its softness it is particularly desirable.

SPRINGS RELATED TO THE YELLVILLE DOLOMITE.

The Yellville dolomite outcrops over nearly the entire area of the Salem upland. Its rôle as a water reservoir is similar to that of the Boone formation. However, there are local beds of shale and argillaceous layers in the Yellville formation, and in some instances they guide the ground water to a point of outcrop. The springs from the dolomite are numerous, but much of the water issues directly into the streams without appearing as springs. The formation as seen in its natural exposures exhibits, especially along the bluffs, solution channels showing the point of issuance of ground water before the streams had cut their valleys down to their present positions. Within the area of the Yellville formation there are many sink holes and caverns. The ground water undoubtedly moves in important channels. At Mammoth Springs, a station on the Memphis Railway on the northern border of the State, the water issues with such volume that it is often spoken of as a small river. It contributes, as do many of the springs of the region, to the natural beauty of the scenery and the enjoyment of pleasure seekers.

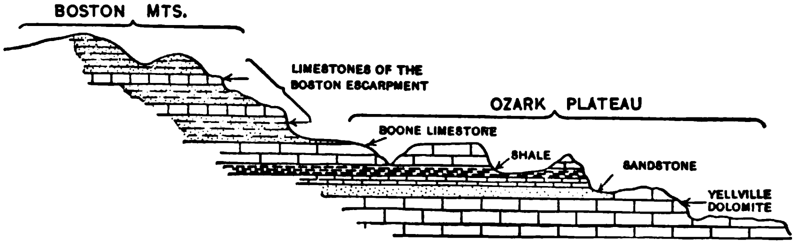

FIG. 33. Diagrammatic section showing principal horizons of springs in northern Arkansas.

Many of the springs of this region are more or less renowned, and some have been frequented for many years as health resorts. Analyses of the waters from some of them have been made, and certain of them are reputed to have medicinal value and in rare instances do contain unusual minerals in solution. It may be said of the springs of the region in general that they are particularly pure and wholesome. As such they are valuable for domestic purposes, and in some instances as a supply for small towns. A few of them are regarded as possessing therapeutic qualities which render them valuable in specific ailments. None of the springs in this region are hot springs. On the contrary, the temperature of them in summer time is such as to render them cool and potable. The country is at present sparsely settled. No doubt more of the springs which are now allowed to run to waste will, because of their surroundings, become valuable as pleasure and health resorts.

NOTES ON THE HYDROLOGY OF CUBA.

By M. L. Fuller.

INTRODUCTION.

The problems of the water resources of Cuba were brought forcibly to the attention of those interested in the island during the period of occupation by the American army. Notwithstanding the great abundance of water on the island as a whole, it was found that in many of the relatively level strips along the shores the supply was frequently both insufficient and of a poor quality. This led, in a considerable number of instances, to the sinking of wells by the War Department. The attention given, both by the Americans and the natives, to the question of utilizing more fully the splendid natural resources of the island will doubtless, under the present improved conditions, lead to the introduction of pure supplies in many villages.

At many of the mineral springs hotels and baths were constructed and resorts developed by the Spanish. Some of the springs are equal to many of the famous spring resorts of Europe and America in natural beauty of surroundings and in the quality of their waters, and will probably in a few years become popular with many Americans. The caves, though having many natural attractions, are in many instances inaccessible, and have been until recently almost unknown to people outside the regions in which they occur.

The purpose of the present notes is to give a summary of the natural and artificial water resources of the island, including town water supplies and springs and the underground drainage with its resulting caverns.

Acknowledgments.—The facts included in the following notes have been drawn from a number of different sources, but in their presentation it is impossible to give separate credit in each case. The portions relating to the topography and geology are mainly based on the "Report on a Geological Reconnaissance of Cuba," made to Brig. Gen. Leonard Wood by C. W. Hayes, T. W. Vaughan, and A. C. Spencer, published in Cuba in 1901; those relating to water supplies from reports of Assistant Engineer O. Giberga, Maj. H. F. Hodges, and Resident Engineer H. F. Labelle, published in "Civil Report of Brig. Gen. Leonard Wood, January 1 to May 20, 1902," volumes 5 and 6; those relating to mineral water from a report by Mrs. H. C. Brown incorporated in the preceding; those relating to subterranean caves and streams from "Island of Cuba," by Lieut. A. S. Rowan and M. M. Ramsey (Henry Holt, New York, 1896); and those relating to wells in part from published reports of the War Department, but mainly from written memoranda furnished directly by that Department to the United States Geological Survey.

GEOGRAPHY AND TOPOGRAPHY.

The island of Cuba is located south of the State of Florida, the meridian of Washington crossing it about 200 miles from its eastern end. The distance of the nearest point of Cuba from Key West is 86 miles. The length of the island is 730 miles, the breadth from 20 to 90 miles, and the area about 43,000 square miles.

In general terms the island may be said to possess a central highland belt, reaching from Cabo de Maysí on the east, first northwestward and then southwestward to Cabo de San Antonio on the west, attaining an elevation of 2,500 feet and becoming somewhat mountainous in places, but elsewhere dropping nearly to sea level.

The surface may be divided into five topographic provinces, three of which are essentially mountainous while the other two are of low or moderate relief. The easternmost of these topographic divisions coincides approximately with the Province of Santiago. In this province, taken as a whole, there are two principal mountain groups. The southern is an east-west ridge, known as the Sierra Maestra, extending from Cape Cruz to the vicinity of Puerto de Guantanamo, and from there continued by a geologically distinct ridge of the same trend to Cape Maysí. The loftiest mountains of Cuba, some of which are higher than any peaks in the eastern United States, occur in this range. The northern range merges with the southern near the eastern end of the province, but diverges westward, the intervening area constituting the undulating plain of the well-known Cauto Valley, which westward merges with the more extended plains of Puerto Principe. The second topographic division corresponds closely with the Province of Puerto Principe, and is made up of plains or rolling open country broken by occasional hills or low mountains rising above the general level. The third division includes the mountainous portions of the Province of Santa Clara. The island is here crossed by a mountainous belt made up of a number of subordinate groups, the highest point of which is 2,900 feet in altitude. The fourth topographic district comprises the western portion of Santa Clara Province, all of Matanzas and Habana provinces, and the eastern portion of Pinar del Rio. This region, like that of Puerto Principe, is made up of low, flat, or rolling plains, broken by occasional hills several hundred feet in height. The fifth division comprises the greater portion of Pinar del Rio, and is characterized by a prominent range of mountains reaching to a height of 2,000 feet. The coast is bordered at many points, especially on the south side of the island, by marshy belts, while the shore is often fringed with reefs and keys.

GEOLOGY.

The structure of the island in a broad way is anticlinal. The geologic axis, which coincides roughly with the topographic axis, is marked by masses of serpentine, granite, and folded and metamorphic slates and schists, on the flanks of which, dipping gradually away, lie the later sedimentary formations. The dip is strongest to the north. Of the later sedimentary beds the oldest appears to be a semicrystalline blue limestone, which may be as old as the Paleozoic. It is, however, only locally developed, the first persistent beds being the hard gray limestones of the Cretaceous. These are overlain by Eocene limestones and glauconitic sands, sometimes interbedded with volcanic rocks, and by a great thickness of limestone, marls, etc., of Oligocene age. During the accumulation of these rocks the land was deeply submerged, at times possibly completely, except for occasional peaks in southern Santiago Province. In Miocene times the land was uplifted above sea level, where it has remained, except for a possible subsidence of 100 feet in Pliocene times and a number of minor oscillations in Quaternary times, during which the Quaternary shelves of elevated reef rocks were formed. The uplift was greatest along the old axis, the result being the tilting of the beds on both flanks.

The limestones, which are the predominant rocks of the island, constitute nearly its entire surface except along the axis of the island. They are in general distinctly stratified, but their internal structure has been greatly changed by the action of percolating waters, nearly all traces of fossils having been destroyed. Their present thickness is from 800 to 1,000 feet. Since their deposition they have been removed by erosion from portions of the higher lands, while in some of the less elevated lands, although they form the surface, they are frequently cut through by streams.

DRAINAGE.

The highlands of the island are characterized by the presence of abundant springs of considerable volume. While a considerable number of these flow from the metamorphic and igneous rocks, the larger springs are from the limestones which cover a large part of the island. The waters are of that extreme transparency which characterizes the limestone springs of the adjacent mainland at Florida. It is from these springs, or in some instances from underground streams, that the surface streams of the island take their rise. The run-off by these streams is very great, as the high rainfall usually occurs as showers of short duration, the water finding its way quickly down the steep hillsides into the streams. The portion of the rainfall sinking into the ground passes into the porous limestone, through which it finds its way by general seepage or by way of caverns and other underground channels back to the streams. In some instances whole streams disappear into the limestone only to reappear near the margin or beneath the sea.

The arrangement of the streams in Cuba is very simple, their courses being nearly all normal to the coast and their lengths, therefore, very short. The divide between the northward and the southward flowing streams lies near the axis of the island, being generally somewhat nearer the north than the south coast. In the eastern and western provinces the divide corresponds with the mountainous belts, but in the central province it falls on a level plain and is extremely indefinite. In the mountainous regions the valleys, while moderately steep-sided, are fairly wide, but where they cut through the tilted plateau along the northern coast canyon-like valleys have been formed. An exception to the ordinary arrangement of streams is found in Santiago Province, where the Rio Cauto, the largest river of the island, has a trend nearly due west. The length of this stream is 150 miles, and it is navigable for shallow craft for a distance of 50 miles.

Lakes are very rare on the island, although a number occur in the midst of the dense vegetation of the marshes near the coast. Many of these are hardly known to the inhabitants themselves. A very few small lakes are also found in the mountains. The most noted of these is Lake Ariguanabo, which lies 20 miles southwest of Habana. Its surface is 6 square miles in area and it is drained by a stream which, after flowing on the surface a short distance, disappears into a subterranean passage. It is inhabited by fish, which are supposed to have worked their way upward to the lake through this passage.

CLIMATE.

The climate of Cuba is tropical and insular. The year is divided into a rainy and a dry season, the former extending from May to October. Two-thirds of the total precipitation, which amounts to about 50 inches at Habana, falls within this period. The rainfall inland is considerably higher. The average temperature for August is from 89° to 91°, while in December, January, and February it is 10° to 15° lower. The temperature of the north coast is somewhat lowered by the persistent northeast trades. The relative humidity is very great, amounting to an average of 80 per cent.

WATER SUPPLY.

CITY WATER SYSTEMS.

Notwithstanding the extremely numerous springs and streams of pure water, few public supply systems have been installed, and these only in the largest cities and towns. In the smaller cities and villages the supplies are obtained from a variety of sources. Shallow wells are generally used where water is obtainable, regardless of the fact that they are almost invariably subject to contamination. Cisterns are frequently used, but generally furnish insufficient supplies to meet the needs of the people. To supply this deficiency water is often peddled about the streets in kegs and other receptacles. Even where pure city supplies are at hand the poorer classes, in many instances, are not inclined to connect with the pipe systems because of the expense, but prefer to continue to purchase their supplies from peddlers. In some towns water has been at times so scarce that it has commanded almost fabulous prices.

Habana.—The first water-supply system for the city of Habana was installed at the close of the sixteenth century, when a dam was built across the Almendares River about a mile above Puentes Grandes, and the water brought to the city through an uncovered aqueduct known as the Zanja Real, which reaches the city at a point near the present reservoir. From this point the zanja divides into many branches, the water ultimately making its way into the bay and sea through Matadero, Agua Dulce, and San Lazaro creeks and the city sewers. The water in this aqueduct is now so contaminated as to be unfit for drinking in the built-up portions of the city, and is at present mainly used for irrigation and power. The water rates paid, however, are so low that the expense of keeping the zanja in repair is greater than the income derived from it.

The second system of water supply dates from 1837, when the Almendares River was diverted at a point about 4½ miles above the city. The water was conducted by a 20-inch iron pipe laid to the city, together with a limited number of distributing pipes, the system being known as the aqueduct of Fernando VII. An attempt was made at filtration, but the methods proved defective and in times of heavy rain the supply was turbid from surface wash. The filters, however, although of an antiquated type, were found by the Americans to be in good condition and were cleaned and maintained, in order that they could be utilized to bring in the Almendares water in case of a break in the Vento aqueduct.

The supply from the river proving insufficient a new system was projected in 1858. By this plan a group of 400 springs near Vento, on the banks of the Almendares, about 8 miles above the city, were enclosed in a masonry structure 150 feet in diameter at the base, 250 feet at the top, and 60 feet deep. Masonry dams were built around the top to keep out the surface wash. The water is carried under the river through an inverted siphon consisting of two heavy iron pipes in a masonry tunnel, and thence by gravity through an underground masonry aqueduct to the Palatino reservoir, about 4 miles from the city. From the reservoir the city is supplied by gravity through a system of distributing mains. The construction of the system met with many interruptions, but the works were finally completed about 1893. The supply is about 40,000,000 gallons a day, against 1,333,000 gallons a day of the earlier system.

In 1886, during the construction of the Vento aqueduct and before its completion and the construction of the reservoirs, a branch main, 20 inches in diameter, was run from the Vento aqueduct at a point opposite the filter beds to those beds, and the water of Almendares River was cut off from the beds and the Vento water supplied to the city through the aqueduct of Fernando VII. Since the completion of the Vento system neither this branch main nor that portion of the aqueduct of Fernando VII south of Palatino has been used. They have, however, been maintained in good condition, so that in case of accident to the Vento system below the branch main the city could be supplied with Vento water through this branch and the Fernando VII aqueduct.

Casa Blanca and Regla were formerly dependent upon cisterns or local wells more or less contaminated, or upon water supplied from the Habana mains, which was carried across the harbor in boats and sold at the rate of 2 cents a gallon. In 1899 an iron pipe was laid across the harbor to a pumping station at Cabana Fortress, from which the water is pumped to a 200,000-gallon tank on the hills, whence it flows by gravity to Cabana Fortress, the barracks, and the town of Casa Blanca. Regla is supplied by a gravity main connected with the Habana supply. A pumping station was installed in 1898 near the Palatino reservoirs for the purpose of furnishing supplies for the camps at Quemados, Marianao, and to Camp Columbia, Aldecoa, Principe, and several hospitals, and other places. A project was also started to supply the town of Arroyo Naranjo from springs at Calabazar. Plans were also made for supplying Pirotecnia, Carmelo, and other localities.

The only large sections of Habana now without Vento water are the higher portions of Jesus del Monte and La Vibora and the high sections of Vedado, all of which will have to be supplied by pumping, as they are above the limits of the gravity supply. Detailed plans and estimates were prepared and submitted for the supply of the former places, at an estimated cost of $36,500, but the work was not undertaken by the Americans on account of the lack of funds. Studies were made for the supply of the higher parts of Vedado.

A concession was granted to a private company by the Spanish in 1894 to supply and sell Vento water to the lower portions of Vedado and Carmelo. Some work was done, but the system was found to be incomplete and in bad condition, and the concession was annulled by order of the governor of Habana in 1899. This order was revoked, however, in 1900. The conditions are still very unsatisfactory.

During the Spanish control cast and wrought-iron pipes, principally the latter, were used for house-service connection, and, owing to the rapidity with which they are destroyed by the salts and acids of the soil, breaks were frequent. Many of the distributary pipes were also old and the connections were frequently faulty and complicated. Many of the valves of the old system were found to be almost entirely destroyed. A large amount of repairs, including the replacement of much pipe, the installation of many new valves, and the inspection of 400 fire hydrants and installation of 100 new ones were made by the Americans.

In certain parts of the city leakage was very great and an investigation was made by the Americans, with the result that the daily consumption was decreased from 35,419,342 to 28,760,800 gallons, or from 144 to 117 gallons per capita. The consumption is still high, especially for the hours between 1 and 2 a. m., when the legitimate consumption should be very small. Probably much of this loss is due to leaks that can not be readily located because of the porosity of the soil, which favors rapid absorption of the leakage.

The regulations governing the water supply of the city do not admit of proper control and regulation of the service. In 1902 the installation of water was made compulsory in those portions of the city that are supplied with mains and the installation of meters was required in manufacturing establishments or other institutions using large quantities of water. This order greatly increased the revenues and secured a more just distribution of charges.

During the American occupation it was observed that for a day or two after a freshet a quantity of turbid water entered the main spring or "taza" at Vento. It was at first thought that this was caused by the river water entering the spring through the valves regulating the overflow, which were not designed to resist pressure from the outside, but experiments made later showed that the trouble was due not only to this leakage, but chiefly to underground connections between the outer springs and the main springs. When the river rises beyond the level of the main spring, the head thus formed forces the water through these connections into the spring. Apparently the only way to prevent this is to build a tight wall around the outer springs and carry it above the highest flood level, or else to tightly cover these springs and provide automatic waste valves which will close when the river rises to the danger point.

During the period of the American occupation the Vento aqueduct and the Palatino reservoirs were maintained in good condition, the reservoirs being thoroughly cleaned at least once a month. These are, however, insufficient in size, holding less than half a day's supply, and should be enlarged. The aqueduct is large enough for present needs, but a new one is desirable to provide for the possibility of accident to the present one. The supply from the springs is ample for present and future needs, and the water is excellent in quality, being almost pure organically, but hard from limestone in solution.

Matanzas.—The city of Matanzas has had an abundant supply of excellent water since 1872. The source is Bello Springs, from 7 to 10 miles from town. As in other Cuban cities, many have failed to take advantage of the public supply but continue to obtain their supply by purchase or from shallow wells and springs.

During the American occupation the problem of supplying the jail was investigated. The water is now obtained from a cistern and pumped into an elevated 23,000-gallon tank, from which it is distributed to the jail for use in baths and closets. Since installing the tank the average daily consumption from the water company's mains has been reduced from between 5,000 and 10,000 gallons to about 500 gallons, the average charges at the same time falling from $95 to $3.85, the latter sum being paid for water still obtained from the company for drinking and cooking purposes. The total cost of the installation was $357.

Cárdenas.—Cardenas has been supplied since 1872 with pure water from a subterranean river about a mile distant. Brackish wells and cisterns are still depended upon by some of the people, while others have until recently purchased their water from street peddlers.

Cienfuegos.—Until a few years ago this city was supplied by cisterns or by peddlers, but waterworks were being introduced at the time of the American occupation.

Guantanamo.—This town was formerly supplied by an underground stream flowing from a cave, but work on a new supply was begun in 1899 by the Americans, who built a dam across Guaso River, 9 miles from Guantanamo. This dam was completed in 1901 and yields a supply of 955,152 gallons of excellent water daily, or 120 gallons per capita. The total cost was $210,166.32. The work was turned over to the municipality in February, 1902.

Puerto Principe.—The water supply of Puerto Principe is derived chiefly from artesian wells, five of which were drilled during the American occupation. Of these, two are in the northern part of the city, one in the western, one in the central, and one in the southern. The two wells in the northern part of the city are each 486 feet deep, situated side by side, and supply about 25,000 gallons of water daily to the public buildings and to the public who call for it. At this place the water is pumped by steam, the pumps being run day and night. At the other wells—one near Carmen Hospital, where a good and abundant supply was obtained at a depth of 188 feet; one in the market place, 207 feet deep, and one at the Matadero, 154 feet deep—60-foot tower windmills, with 10,000-gallon tanks, have been erected. The tanks are placed 30 feet above the ground.

Santiago.—Santiago has long been supplied with water from Boniato River, a neighboring stream, the water being conducted to the city by an aqueduct. This was cut by the American army during the siege of the city, but was repaired during the American occupation. Prior to this time the supply was only about 9 gallons per capita from June to February, while in March, April, and May the stream was so low that only 2.5 to 5 gallons were obtainable. After certain improvements had been made, measurements showed the supply capable of yielding 800,000 gallons daily, or 18.6 gallons per capita, but the supply was decreased 162,000 gallons daily by the necessity of cutting a part off from the lower part of the city in order to secure sufficient head to supply certain of the higher portions. An additional supply of 30,000 gallons was obtained by cleaning and repairing the old reservoir built in 1860 and connecting it with the city mains. The northern part of the city was supplied from the reservoir, while the southern part was supplied by the direct mains. Pumps were also installed to increase the supply in dry seasons.

As approximately 3,000 people live on the stream within a mile of the intake the water was badly polluted and there was constant danger of epidemics. This, taken in connection with the deficiency of supply, made it imperative to look for a new source. Detailed investigations were accordingly made by the Americans, the country for 30 miles around the city being examined with a view to procuring a new supply. The sources considered were (1) a gravity supply from Baconao River; (2) a gravity supply from Cauto River, and (3) a pump supply from wells in the San Juan Valley.

In the proposed Baconao system the water would be taken from a point about 21 miles above the mouth of the river, from which it would be conducted 19 miles to Daiquirí and 18.5 miles farther to Santiago. Nearly the whole of the line is of easy access, and the location would require very little costly road making. The estimated total cost was $2,844,812 and the annual cost of operation $169,000.

A supply from Cauto River could be brought in by pumping through the Maniel or Rio Frio Pass from a point about 2½ miles below Dos Palmas, a distance of 25 miles from Santiago. The country is favorable to the construction of a conduit, and good locations for dams and power stations are available. The estimated cost was $1,451,127, and the annual cost of operation $105,000.

The preliminary surveys having shown that still better results would be obtained from a well system in the San Juan Valley, a detailed investigation in that region, including the drilling of test wells, was undertaken. The portion of the valley under consideration lies just south of the Sierra Maestra, and drains to the sea through a gorge 500 feet wide at La Laguna. The underflow through the river gravels is very high in some of the branches, and the water is of good quality, notwithstanding the river waters themselves are frequently much polluted. The well sections show: (1) A surface layer of brown clay and vegetable matter from about 4 to 16 feet in depth; (2) a water-bearing stratum of sand, gravel, bowlders, and broken coral rock, 11 to 30 feet thick, with an average of 25 feet; (3) blue, yellow, or brown clay, 5 to 20 feet thick; and (4) a series of sands, gravel, broken coral rock, clay, etc. The coral bed rock has not been reached except along the borders of the valley, where it is near the surface. The following record may be given as typical:

Record of well at Santiago, Cuba.

Strata.	Thickness of strata.	Depth from surface.
Soil	21	21
Fine sand	16	37
Gravel	13	50
Coarse gravel	6	56
Yellow clay	14	70
Blue clay	6	76
Fine sand	17	93
Sandstone	7	100
Coral rock	18	118
Hard coral rock	8	126
Fine sand	9	135
Yellow clay	8	143
Sand and gravel	7	150
Clay	5	155
Sandstone	6	161
Gravel and sand composition	9	170
Total	....	170

The area of the local underground reservoir to be drawn upon for the supply is estimated as 3½ square miles, and the probable yield computed as from 1,235,000 gallons a day in dry seasons to perhaps 2,434,000 gallons in wet seasons. The average rainfall is estimated at about 60 inches, the run-off as 13.5 per cent, and the total supply of underground storage 23,000,000 gallons a day. If 60 per cent of the 15 feet of storage gravel is utilized the supply is good for 410 days, which, considering the fact that the dry season lasts only four or five months, is amply sufficient. The water of the lower gravels can also be utilized in case of any deficiency of the upper supply. Infiltration galleries, gang-tube wells, and large caisson wells were considered as methods of collecting the water, the latter being finally recommended. San Juan Hill was selected as the best site for the pumping plant. An examination of the water by G. C. Whipple, of Brooklyn, N. Y., showed slight organic matter, low free ammonia nitrites and nitrates, and high chlorine, as well as carbonates and sulphates—especially the former. Storage in the dark, to prevent algous growth, was recommended. The cost of installation was estimated at $408,650 and that of operation as $92,000 annually. Both figures are much lower than either of the other systems proposed.

Manzanillo.—This town formerly had a water system deriving its supply from the river Yara, but it proved unhealthful and was abandoned. Cisterns now furnish the main supply.

SPRINGS.

Owing to the great porosity of the limestone which forms the surface over a large part of Cuba, and which rapidly absorbs and almost as rapidly discharges its waters, springs are very numerous. They are of all sizes, from small rills up to almost river-like streams. Some of the springs seep from the porous limestone, but many of them issue from more or less cavernous orifices. They issue at all altitudes, from the higher portions of the hills down to the lowland border, or even at sea level. It is probable that the marshy tracts bordering the south coast at many points are in part due to the emergence of the underground water through the limestone. Not all of the water comes to the surface of the land as springs, but some passes outward and emerges from the sea bottom along the coast, where in many instances the fresh water can be seen bubbling up through the salt water. Such springs occur in Habana Harbor and at many other points. The fresh water which emerges as copious springs on some of the keys is probably of the same origin, coming from the mainland through subterranean passages in the limestone.

Most of the spring waters of the island are highly calcareous, but are usually not otherwise especially high in mineral matter. They form pure supplies for a number of cities, including Habana, Matanzas, and Cardenas, while at other points not having public supplies, as at Marianao, the water is obtained from adjacent springs and sold through the town. Although by far the larger number of springs are of the pure calcareous type, there are a number of mineral springs upon the island. These are described under "Mineral waters," below.

SUBTERRANEAN STREAMS AND CAVES.

Probably very few regions in the world so abound in caves and subterranean passages as the island of Cuba. The porous limestone permits a free entrance of water which, by its passage, dissolves out caverns of various shapes and sizes. Although the underground passages are very numerous they are not usually large, and the caves generally lack the great beauty of many of the stalactite-hung caves of the harder types of limestone.

Many streams disappear from the surface into the limestone. Of such streams the Rio San Antonio, in the province of Habana, is the most noted. This stream issues, with a width of several feet and a strong current, from Lake Ariguanabo, flows a short distance through the town of San Antonio de Los Baños, and then enters a cavern and disappears from the surface. In a similar manner the Rio Guanajay flows on the surface for about 12 miles and then disappears into the limestone near the village of San Andrés. The Rio Jatibonico del Norte rises in the Sierra de Jatibonico and alternatelv disappears and reappears in a succession of cascades. The Rio Mayari, near Santiago, and the short stream called Moa both pass through caverns in their courses. Many other streams throûghout the island pass at one point or another in their course under natural rock arches.

Among the larger or more noted of the caves are those of Resolladero Guacanaya, in Guaniguanico; María Belén, in the Sierra de Añafe; that of Cotilla, near San José de las Lajas, 15 miles southeast of Habana; the magnificent caves of Bellamar in Matanzas; the caves of San José de los Remedios; and the caverns of Cubitas, of Gibara, of Yumurí, of Holguín, and of Bayamo; while north of Guantánamo are the noted Monte Líbano caverns.

The Bellamar caverns, 3 miles distant from Matanzas, are extensive and possess a high temperature. The air is supposed to have certain curative properties, and the caves are resorted to by invalids. At Baracoa are caverns that have an unusual development of stalactites and contain animal remains of unknown date.

MINERAL WATERS.

Cuba possesses some true mineral springs, although these are small in number compared with the common springs. Little use is yet made of them for drinking purposes, and almost nothing is done in the way of shipment. On the other hand, however, they are extensively used for bathing at various watering places and health resorts. The portion of the following notes relating to the province of Pinar del Rio and to a part of Habana Province was compiled by Mrs. H. C. Brown for the report of Brigadier-General Wood.

Province of Pinar del Rio.—Of the numerous health resorts of Cuba. that of San Diego de los Baños enjoys a particularly large share of popular favor. The town was founded in 1843, and before the numerous wars decimated the population contained 8,007 inhabitants, but at present it counts little more than a quarter of that number. The left bank of the river which flows beside the town bubbles with sulphurous springs, some warm, others cold. The best known of these are called Templado, Tigre, and La Paila. On the authority of Dr. José Miguel Cabarrouy, medical director of the baths, the following analysis of the waters of Templado and Tigre is given:

Analysis of mineral water at San Diego de los Baños, province of Pinar del Rio, Cuba.

	Per cent.
Hydrogen sulphide	0.152
Carbonic acid	.062
Sulphate of lime	.974
Chloride of sodium	.032
Bicarbonate of magnesia	.080
Alumina	.006
Total	1.306

The density of these waters is given as 1.014. They contain, besides the ingredients noted above, undetermined quantities of silicic acid, carbonate of iron, nitrogen, oxygen, and organic matter. The Templado produces 860,000 liters in twenty-four hours, and the Tigre 240,000, without any variation according to seasons. The water is colorless, has the disagreeable odor of sulphuretted hydrogen, and tastes slightly sulphurous. It has a temperature of about 34° C.

The spring called La Paila shows the following analysis:

Analysis of water from Mineral Spring La Paila, province of Pinar del Rio, Cuba.

	Per cent.
Sulphate of lime	1.068
Chloride of sodium	.022
Bicarbonate of magnesia	.120
Carbonic acid	.084
Alumina	.012
Total	1.306

The waters, which have a temperature from 22° to 25° C., show traces of sulphuretted hydrogen, silica, carbonate of iron, oxygen, nitrogen, and organic matter.

The waters of San Diego de los Baños have proved to be of special value in cases of skin disease, rheumatism, and nervous affection. The place has a wide patronage and makes pretensions as a popular resort.

Springs of mineral water are also reported from the municipal district of Mariel. In the district of San Cristóbal are springs called Soroa.

Province of Habana.—The most prominent springs of Habana Province are found at Guanabacoa, Madruga, and Santa María del Rosario.

The principal use of the mineral water at Guanabacoa is made by the Santa Rita baths, which are constructed of stone and are popular with many of the residents of Habana.

Madruga has warm and sulphur baths, supposed to possess curative properties in cases of skin disease, and also springs of mineral water that is reported to be excellent for stomach troubles. The town is a popular watering place, having several hotels which are extensively patronized from March to October.

The baths of Santa María del Rosario are famous for their medicinal qualities. The principal springs that supply the baths are three in number. The waters of the first, which is called Mina, Templado, or Palmita, issues from an orifice in the rock 3.80 meters below the surface. The water from this spring is clear and colorless, has the odor of sulphuretted hydrogen, and is disagreeable to the taste. It is cold, reaching a temperature of only 22° C. Its reaction is alkaline. The water of the second spring, called Tigre, comes from a well 6.04 meters deep. Although clear and transparent, it has a light yellow color, an odor more pronounced than that of La Mina, and a stronger taste than the first. Its temperature is 21.5° C., and its reaction is freely alkaline. The spring called La Paila is only a meter deep. The water is clear and colorless and has an odor and a taste more pronounced than the water of the other two springs. It is colder, having a temperature of 19.50° C. Analysis of the waters shows appreciable amounts of sulphur and hydrogen sulphide.

Isle of Pines.—There are many natural springs all over the Isle of Pines, and those of Santa Fé have an established reputation for their curative properties, both in Cuba and abroad. The waters are said to be particularly rich in iron and magnesia, and contain also oxygen and carbonic-acid gases, chloride of sodium, sulphate of lime, carbonate of lime, chloride and nitrate of calcium, and silica. The temperature of the waters is generally about 82° F. Some of the larger springs flow a stream of water the size of a man's body.

WELLS SUNK BY THE WAR DEPARTMENT IN CUBA.[a]

Cienfuegos.—A well was sunk by the army authorities at this point to a depth of 111 feet. A good flow of water was obtained. The following is a record of the materials penetrated:

	Feet.
Clay and sand	1- 86
Blue clay	87-101
Blue clay and gravel	102-111

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[a] Compiled from reports and memoranda of the War Department.

Gibara.—Two wells were drilled at this point by the Bacon Air Lift Company, at a cost of $2,500. The first well was started August 8, 1900, but was abandoned at a depth of 212 feet, because of the telescoping of the pipe. A new well was then started. This obtained water at 75 feet and again at 90 feet, but the flow was small. At 560 feet a strong flow of salt water was obtained and the well was then abandoned. The diameter of the casing was 8 inches at the top and 6 inches at the bottom. The failure of this well was seriously felt, as the cistern supply on which the town depended was very insufficient. Several other wells were drilled to a depth of about 600 feet with like results.

Guanajay.—A well was here sunk to a depth of 40 feet, which resulted in a failure.

Holguin.—Most of the supplies at this place are from surface wells and are satisfactory in amount except at times of drought. The water is derived from disintegrated granite and is somewhat liable to surface contamination. It is hard and contains considerable mineral matter. During the American occupation the public wells were deepened and cleaned, and windmills were erected. An artesian well was begun on November 20, 1900. A strong flow of excellent water is reported to have been obtained at 61 feet, but was cased off with the hope of finding more abundant water at a deeper level. Hard water was encountered, however, and the bit broke at 160 feet, at which depth the well ceased. A later well went to a depth of 400 feet, a small amount of water being found at a depth of 125 feet, but none below. A steam pump and tank were put in, and the well gave a supply sufficient for the barracks, but not for the town.

Matanzas.—Wells were drilled by the Government to depths of from 330 to 400 feet, but resulted in failure.

Pasa Cabellos.—The wells sunk by the War Department at this point were 78 feet deep and gave 60,000 gallons during a ten-hour pumping test.

Pinar del Rio.—A well begun by the War Department on April 5, 1899, was drilled to a depth of 285 feet, but resulted in a partial failure, the water being very hard and carrying some sulphur. The formation from a few feet of the surface to the bottom of the well is stated to consist of alternate layers of soft and hard rock, parts of which approach clay in character. Water in small quantities was found at 35, 80, and 145 feet, and in smaller amounts between 200 and 285 feet. There are 158 feet of 6-inch casing in the well. The water rises within 95 feet of the surface. The well will not furnish more than one gallon a minute and is regarded as a failure, as the well is pumped down to 150 feet in a half-hour with an ordinary hand pump. The water rises to its former level in about thirty minutes. It cost about $1,800.

Puerto Principe.—A number of wells were drilled by the War Department at this point. The first one of importance appears to have been started on May 1, 1899. It is located on the grounds on which the cavalry barracks were situated in the city of Puerto Principe, and its mouth has an elevation of 337 feet above sea level. The ground in its vicinity is practically level. During the first 30 feet the well passed through decomposed granite, but from 30 feet to the bottom it was drilled through hard crystalline rock of various colors and hardness. The first water of consequence was struck at 95 feet, and rose to within 30 feet of the surface. The boring was continued, however, to a depth of 264 feet without obtaining any decided increase in the amount of water. At this point the drill was once more withdrawn and a pumping test made lasting two days. Five hundred gallons were pumped hourly without lowering the working head of the water more than a few feet. It was, however, decided to push the well to a greater depth. A month later, when the well had reached a depth of 457 feet, the drill was again withdrawn, and the well was tested by a 2-inch pump attached to the walking beam of the well rig and making 30 strokes to the minute. It extended 150 feet down the well, and during the two days an average of 502 gallons of water an hour was raised. At the beginning of the pumping the water stood 30 feet from the surface, but fell rapidly during the first hour, at the end of which it stood at a depth of 43 feet from the surface. During the continuance of the pumping, however, doubtless by reason of the removal of silt from the pores of the adjacent rock, the water slowly rose until, at the end of the fifth hour, it had reached a level of 41 feet from the surface. On standing over night the water returned to its original level of 30 feet, but during the first hour's pumping again fell to a level of 41 feet below the surface. On August 30 the drills were replaced and the well was pushed to a depth of 474 feet. Previous to the sinking of the well, the supply of the barracks had been obtained by hauling water, all of which had to be boiled, from a creek 3 miles away. The test of the well proved that it would supply more than 500 gallons an hour without lowering the water more than 11 feet from its normal level, and it was estimated that from 2,000 to 3,000 gallons an hour could be obtained without lowering the level more than 30 feet. The water is clear, without sediment, and is sparkling and palatable. An analysis of water made at the Military Hospital No. 1 at Habana is given below:

Analysis of water from Puerto Principe.

Odor, none; taste, faint saline; color, no color, very clear; some matter in suspension composed mainly of precipitated salts.

	Parts per 1,000,000.
Free ammonia	None.
Albuminoid ammonia	None.
Chlorine, 0.2	2

	Parts per 1,000,000.
Sulphuric acid as sulphates	35
Sulphureted hydrogen	None.
Total solids	305
Phosphoric acid	Trace.
Silicic acid (silicates)	22
Iron, none; other metals not tested.	
Calcium	69
Magnesium, pyrophosphates	105
Potassium and sodium, somewhat in excess.	

This water is free from harmful materials and is suitable for all domestic purposes.

The water was piped to the barracks and furnished a satisfactory supply. In addition a considerable amount was shipped to Nuevitas by rail.

A second well was begun October 10 and completed December 15, 1900. Its diameter was 8 inches, and it was drilled to a depth of 202 feet. The supply proved ample, and is used in the public buildings of the vicinity. The water stands 135 feet below the surface. Good water was found above 200 feet, but the deeper waters are reported to be brackish. Another well was begun in the market place December 15, 1900. Still others have been described under water supplies.

A well on a proposed site for a military post, presumably near Puerto Principe, is given in the reports of the War Department. It was 8 inches in diameter and 510 feet deep, the water rising to within 8 to 12 feet of the surface. The supply is reported to be of excellent quality.

Santiago.—The army officials report that there is good reason to believe that an abundant supply of water can be obtained from artesian wells along the south coast of Cuba at this point. An examination of the San Juan Valley shows a gathering ground with slight run-off, the remainder reaching the sea by subterranean drainage. It has been proposed to intercept this by tunnels. Some of the shallow wells obtain large flows, but unless carefully located are liable to become contaminated by seepage from the surface. One well, 14 feet in depth, is reported to have so large a flow that it could not be kept down by a pump of 500 gallons capacity.

Triscornia.—An 8-inch well sunk at this point to a depth of 401 feet obtained only a limited supply of water more or less impregnated with salt and unfit for general use.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, Director

PRELIMINARY REPORT

ON THE

UNDERGROUND WATERS OF WASHINGTON

BY

HENRY LANDES

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 4, 1904.

SIR: I have the honor to transmit herewith, for publication in the series of Water-Supply and Irrigation Papers, a preliminary report descriptive of the underground waters in the State of Washington, prepared by Mr. Henry Landes under the direction of Mr. N. H. Darton, geologist in charge of the western section of hydrology.

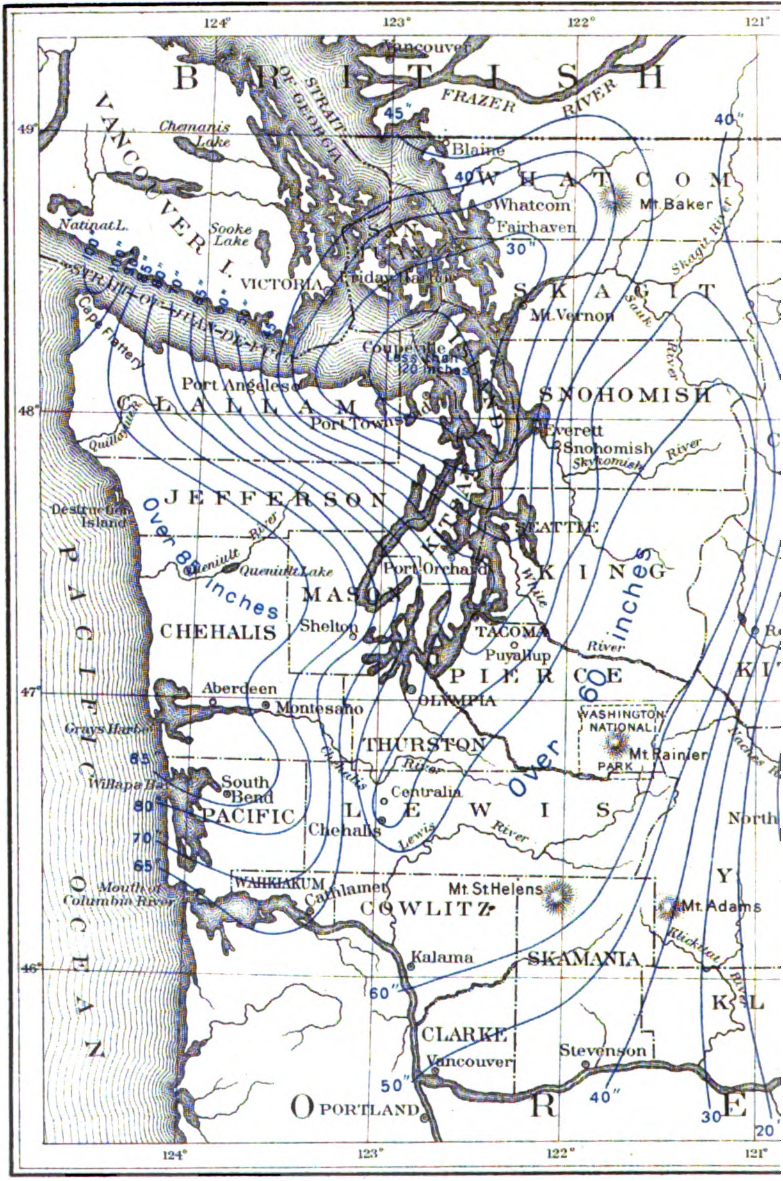
It is believed that the report is a valuable contribution to the knowledge of the water resources of the State.

Very respectfully,

F. H. NEWELL,
Hydrographer in charge.

HON. CHARLES D. WALCOTT,
Director United States Geological Survey.

U. S. GEOLOGICAL SURVEY



——— Mean total precipitation

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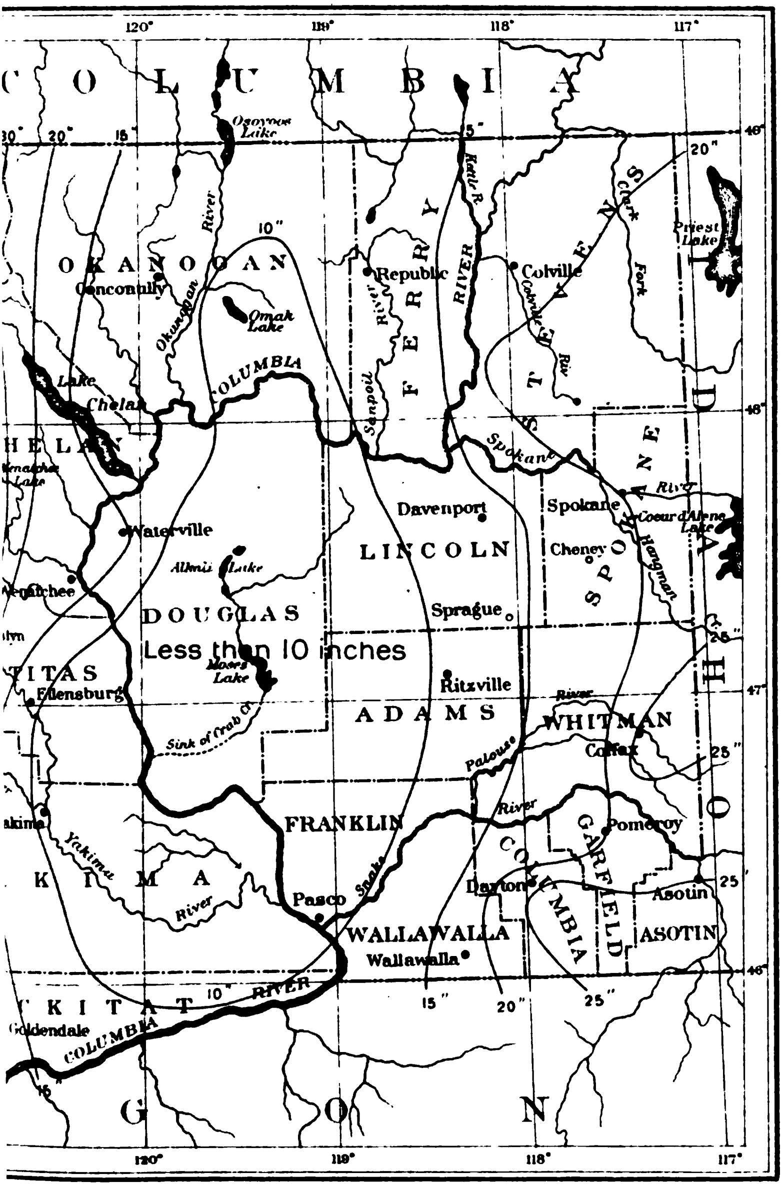

(Corrected to December, 1898)

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PRELIMINARY REPORT ON THE UNDERGROUND WATERS OF WASHINGTON.

By Henry Landes.

INTRODUCTION.

This report contains a brief account of the water resources of Washington as represented by municipal supplies, deep wells, and springs. For each county a general statement is made, giving the location, rainfall, and most striking features of topography and geology. Following this are detailed statements which give data concerning the municipal systems, deep wells, and springs, and which have been secured entirely by correspondence. The blanks sent to the clerks or other officials of the cities and towns regarding municipal water supplies were practically all filled out and returned, so that this information is complete to the present time. The blanks for the deep wells were not returned as generally as was desired, but almost every section of the State where such wells occur is represented, and those described may be taken as types of their kind in each county. Springs occur so very generally throughout the State that only a small fraction of them may be said to be represented in the blanks filled out and returned, but, as in the case of the wells, those mentioned are typical of their class, and it is only necessary to recall that the number given in every county may be multiplied many times. Every effort has been made to eliminate inaccuracies.

No general statements are made concerning the rainfall, topography, and geology of the State as a whole, since these are given for each county. A rainfall map is included in order to show at a glance what the precipitation is in any section, also the contrasts between one part of the State and another.

ADAMS COUNTY.

General statement.—Adams County lies south and east of the central part of the State, on the line of the Northern Pacific Railway, between Columbia River and Spokane. The topography is that of a gently sloping plain, descending from a height of 1,900 feet in the northeast corner to 700 or 800 feet in the southwestern part as Columbia River is approached. The plain-like character of the surface is modified by occasional valleys locally known as "coulees." The drainage is to the south and the southwest, toward Snake and Columbia rivers. Cow Creek is the principal stream; the other streams as a rule are intermittent and are active only in the late winter and spring months.

This county lies within the dry region of central Washington, where the precipitation is light and is confined to the winter and spring months. In the western half of the county the average yearly rainfall is 10 inches or a little less, while in the eastern half it is from 10 to 15 inches. There is a regular increase in the amount of rainfall with the increase in elevation, and hence the precipitation is greater in the northeastern part of the county than in the southwestern portion, and there is more rain in uplands than in the valleys.

The Columbia River lava, or basalt, is the principal rock in Adams County. It forms the bed rock everywhere except in the southwest corner, where the Ellensburg beds, composed of sands and clays, appear. As a rule the rocks are covered with a thick coating of soil, the exceptions being the valley sides and occasionally the valley bottoms. The soil is fine grained, of good quality, and very productive when supplied with the proper amount of moisture. Grazing and wheat raising are carried on very successfully in nearly all parts of the county.

Despite the small rainfall, there is little or no difficulty in securing a good supply of water for domestic purposes. At depths of from 300 to 500 feet wells yield large quantities of good water. The water-bearing strata are usually layers of very porous or cellular basalt. Wherever such layers outcrop along the border of a valley, springs are commonly found.

Municipal systems.—Ritzville is the only town in the county reported as having a water-supply system. The water is obtained from a well having a depth of 385 feet. In this way a supply of good water is secured. The water level in the well does not vary during the day or year and is not affected by pumping. The water is pumped into reservoirs and is distributed by gravity throughout the town. Besides serving as a domestic supply, the water is used in irrigating the lawns and gardens.

Deep wells.—Besides the well which supplies Ritzville, another deep well has been drilled at the same place by the Northern Pacific Railway Company. This well has a diameter of 8 inches and a depth of 355 feet. The water column stands at a height of about 240 feet. There is no variation in the water level during the day or year, and it is affected slightly by pumping. It is used by the railway to obtain water for locomotives.

At Cunningham a well has been drilled by Thomas and James O'Hair. This well has a diameter of 6 inches and a depth of 426 feet. The water column stands at a height of 356 feet and remains stationary throughout the year. This well was drilled at a cost of $1,066. A wind pump was erected at a cost of $290. The above wells serve as a type for those of Adams County.

Springs.—As a type of the springs found in Adams County, the one owned by G. W. Bassett, near Washtucna, may be noted. The water issues as a stream from the honeycombed or porous basalt, and varies but little in quantity during the year. It is sufficient to supply the town of Washtucna, and some of it is used for irrigating purposes as well. The water is soft, carries no sediment, and has no unpleasant taste.

Along Cow Creek, a tributary of Palouse River, in the eastern part of the county, there are a number of good springs.

ASOTIN COUNTY.

General statement.—Asotin County lies in the extreme southeast corner of the State. It is in the main a plateau region, deeply dissected by canyons. The higher parts of the plateau have an elevation of about 5,000 feet above sea. The canyon of the Snake, along the eastern and a part of the northern boundaries of the county, has a depth of 3,000 to 4,000 feet. Leading into the larger canyon from the southwest are the smaller canyons of Grande Ronde River and Asotin Creek.

The average rainfall is 25 inches and is sufficient to afford an ample water supply. On the higher parts of the plateau the precipitation is sufficient to produce a forest growth of firs, pines, and other coniferous trees. On the lower parts of the plateau bunch grass grows luxuriantly and it is only in the deep valleys that irrigation is necessary.

The bed rock is basalt, except in occasional instances where the streams have cut through the lava and exposed the underlying granites and other crystalline rocks. The soil is very thick and, since it is of basaltic origin, is of good quality.

Only in the valleys has the county been settled to any degree. In the deeper valleys, as that of the Snake, irrigation is necessary in order to produce fruit, vegetables, and other products, but for this purpose there is an ample supply of water at hand. Water from Asotin Creek is used to irrigate a large area of flat land at Clarkston, and a sagebrush plain has been converted into an oasis of alfalfa meadows, fruit orchards, and vegetable gardens. In the gravels and sands of the valleys good water may be had from wells that vary in depth from 20 to 50 feet.

Municipal systems.—Asotin, the county seat, is situated on Snake River at the mouth of Asotin Creek. The water supply of the town comes primarily from Asotin Creek, but some dependence is placed on wells and cisterns. The creek rises in the Blue Mountains and carries pure, clear water without any contamination. Besides serving as a domestic supply the water is used for the irrigation of lawns and gardens. The supply is sufficient for the present and in all probability for all future needs.

Clarkston, on Snake River opposite Lewiston, also gets its supply of water from Asotin Creek. The water is carried by a flume 16 miles in length to a point on the hillside immediately above the town and from there is distributed by pipe lines. At present this forms the sole supply for the town, but a deep well is being bored as a possible additional source of supply. An analysis of the water of Asotin Creek made by Professor Fulmer at Pullman on January 29, 1903, showed 6.18 grains of solid matter in each gallon of water. The solid matter was found to be wholly free from objectionable qualities.

Along Snake River, especially in the vicinity of Asotin, are a number of wells which range in depth from 20 to 35 feet. The water is obtained from gravel and sand and is of good quality. This water supply is intimately connected with the river, as the water in the wells and in the river is always at the same level.

CHEHALIS COUNTY.

General statement.—Chehalis County lies on the western border of the State, fronting the Pacific Ocean. The coast line here is irregular, the most marked indentation being Grays Harbor. From the narrow belt of sand dunes along the coast the surface rises by irregular hills until the low mountains of the Coast Range are encountered on the eastern border of the county. Chehalis and Queniult rivers flow in broad valleys from east to west across the county. The region between these streams is drained by Humptulips River, which flows southwest and empties into Grays Harbor.

Along the coast the yearly rainfall averages about 90 inches, but inland it decreases gradually, dropping to 65 inches at the extreme eastern edge of the county. Practically the whole county is covered with a luxuriant growth of vegetation, the only exceptions being the small areas of outwash glacial gravels, commonly known as "prairies," where but few trees have yet begun to grow.

The rocks of Chehalis County as far as known are of Tertiary age. Marine Eocene fossils have been identified at Porter and Elma, in the eastern part of the county, and marine Pliocene fossils have been found at Granville, at the mouth of Queniult River. The Tertiary rocks are chiefly clastic, consisting of beds of clay, sand, and gravel. Occasionally they contain a small igneous dike, usually of basalt. Nearly all of the county north of Grays Harbor and Chehalis River has been glaciated, and the glacial till, with layers of sand and gravel, is very thick.

The very heavy rainfall yields an abundant supply of water for every purpose. The lakes and the deep porous soil are great storage reservoirs, which feed the streams at all seasons and give them an even flow. The only contamination is due to the decay of vegetal matter in the streams and lakes. In the glacial sediments and in the gravels and sands of the river valleys excellent water may be had from wells of moderate depth. It is not likely that deep wells will ever be necessary in order to afford a supply of water in any part of the county. Since the sedimentary rocks above mentioned are known to be folded, it is possible that artesian basins have been formed, within which flowing wells may be secured by drilling.

Municipal systems.—Aberdeen, at the head of Grays Harbor, gets its supply of water from a creek. The quantity obtained in this way is hardly sufficient for present needs, and water from another creek near by will soon be used. The system of waterworks used is that of direct pressure. As a rule the wells do not yield good water, since in digging them marine deposits of mud and sand are penetrated.

A sanitary analysis of the Aberdeen city water was made April 14, 1901, by Prof. H. G. Byers, of the University of Washington, with the following result:

Analysis of water from city well at Aberdeen.

[Parts per million.]

Total solids	75.69
Volatile solids	12.50
Nonvolatile solids	63.19
Nitrogen as nitrites	None.
Nitrogen as nitrates	.090
Nitrogen as free ammonia	None.
Nitrogen as albuminoid ammonia	.021
Oxygen consumed	.966
Chlorine	6.50

The water supply of Cosmopolis is obtained chiefly from wells, but in part from some creeks owned by the Grays Harbor Commercial Company. From the creeks to the town a gravity system of waterworks has been installed. The water is soft, of good quality, and is ample for present needs and probably for all future demands.

Hoquiam, on Grays Harbor, secures its water supply from the headwaters of Little Hoquiam River, which affords a supply of good water sufficient for present and future needs. The water is pumped into a reservoir and then distributed by gravity. Besides serving the domestic demands the water is also used as a boiler supply. Practically no wells are used in the city, especially in that part which is situated on the tide flats.

Montesano, the county seat of Chehalis County, obtains its water supply from some springs north of the city. The supply is sufficient for the present, but some other source may be necessary in the future. From the springs the water flows into a reservoir and is then distributed by gravity. The water is of good quality and there are no sources of contamination. In Montesano a few wells have been dug, usually about 35 feet in depth. The water-bearing stratum is gravel. The water from the wells is good and may be obtained in large quantities. The water level varies only in the dry summer months, when it falls somewhat.

Ocosta, a town of about 300 inhabitants, on the southwest shore of Grays Harbor, obtains a town supply from wells and springs. The water is of good quality and ample for present needs. The wells have an average depth of 50 feet and the water is obtained from beds of sand. The sand is overlain by clay, so that there is no contamination from the surface. The water level in the wells is somewhat lower in summer than in winter.

CHELAN COUNTY.

General statement.—Chelan County lies a little north of the center of the State, and extends from the summit of the Cascade Mountains southeast to Columbia River. The topography is very rugged, since it includes some of the most broken parts of the Cascades. From the northwestern border of the county, which has an altitude of 7,000 to 8,000 feet, the surface slopes southeastward to the Columbia, where the elevation is only about 700 feet above the sea. The streams flow in deep valleys or canyons, and the divides are very sharp and lined with rows of peaks. There are three prominent drainage systems, all having northwest-southeast courses. Beginning at the north these are Stehekin River and Lake Chelan, Entiat River, and Wenatchee River.

The rocks of Chelan County are mainly granites, gneisses, schists, and other crystallines. The principal exception is the sandstone of Eocene age in the southern part of the county. The sandstone is of lacustrine origin and forms a belt reaching from Wenatchee to Leavenworth in an east-west course and from the southern border of the county northward for about 30 miles.

The rainfall is greatest along the extreme western border, or in the region of the highest mountains, where it is from 40 to 60 inches a year. In the descent eastward it decreases rapidly until in the valley of the Columbia it averages but 15 inches yearly. In the mountains much of the precipitation is in the form of snow, and along the summit of the Cascades are many glaciers. The snow-fed mountain streams carry an abundance of the purest water, and in all parts of the county is an excellent water supply. On the alluvial fans and terraces along Columbia and Wenatchee rivers large tracts are now under successful irrigation, the water being supplied by the mountain streams.

Municipal systems.—The town of Chelan has obtained its water in part from springs and in part from Lake Chelan. A system of waterworks is now being installed whereby the water from the lake will be pumped into reservoirs and then be distributed throughout the town by gravity. As the water of the lake comes from the snow fields and streams of the high mountains, and is not contaminated, it is exceedingly pure and healthful. Besides serving as a domestic supply, a large amount of water will be used for irrigation within and about the town. Repeated efforts have been made to obtain water from wells, but although depths of 100 feet were reached no successful wells have been dug on the town site.

Lakeside, at the southern end of Lake Chelan and near the town of Chelan, has in the past depended upon wells for its water supply. Like the town of Chelan, it has under construction a system of waterworks which will draw the supply from the lake.

Wenatchee, the county seat of Chelan County, situated on Columbia River at the mouth of the Wenatchee, obtains its supply of water from a creek which flows out from the Cascade Mountains. This supply is sufficient for present needs, but must be supplemented by something better in the future. Besides its use as a house supply, the water is extensively used for irrigating lawns, gardens, and orchards. There are no successful wells in the region about Wenatchee.

Springs.—In the eastern part of the county a number of springs are employed for domestic supply and for irrigation. The spring owned by George Brisson, which may be regarded as a typical one, issues as a stream from a porous basaltic rock. The water is of good quality, carries no sediment, remains constant for the most part, but decreases somewhat in flow in the autumn.

CLALLAM COUNTY.

General statement.—Clallam County lies in the extreme northwest corner of the State, and has a frontage on both the Pacific Ocean and the Strait of Juan de Fuca. It includes the northern half of the Olympic Mountains, the highest peak of which, Mount Olympus, stands on the southern border of the county. The Olympics are rugged, deeply dissected mountains, and reach outward almost to the coast, leaving a narrow belt of hills immediately along the shore. This belt is much wider along the Pacific coast than along the strait. The highest mountain peaks are from 6,000 to 8,000 feet above the sea.

The greatest rainfall in the State is at Cape Flattery, where the average for the year reaches 100 inches. From this point eastward the precipitation decreases regularly, until at the eastern border of the county it is from 20 to 30 inches per year. In the highest mountains much of the precipitation is in the form of snow, and the snow fields and glaciers serve as reservoirs from which the streams are fed during the summer months. The great abundance of pure mountain water will not only serve as an ample supply for all municipal and domestic requirements, but will afford excellent water power. All parts of the county except the highest mountains are densely forest clad, and the forests are eminently helpful in retarding the run-off and equalizing the flow of the streams from season to season.

In a belt varying from 10 to 20 miles in width, extending along both the north and west coasts, the rocks are of Tertiary age and represent marine sediments. Eocene or Oligocene fossils have been identified along the Strait of Juan de Fuca between Twin River and Gettysburg, and fossils that are probably of upper Miocene age have been found near the mouth of the Quillayute River on the west coast. The Tertiary rocks are all sedimentary, consisting chiefly of conglomerates, sandstones, and shales. Within these rocks a good supply of water may be had from comparatively shallow wells.

To the south and east of the belt of rocks above mentioned, within the higher Olympics, the rocks consist of schists, slates, and other metamorphics, with great intrusions and extrusions of igneous rocks. The age of these rocks and their relations to the sedimentaries above described have never been determined. Along the northern border of the county the glacial sediments are commonly very heavy, and from these it is usually easy to secure good water by means of wells from 20 to 40 feet in depth. There are many large lakes within the county, such as Ozette and Crescent, which are reservoirs of the purest water. Lake Crescent is a very deep lake, at the border line of the high mountains, with water of extraordinary blueness and purity.

Municipal systems.—The water supply of Port Angeles, the county seat of Clallam County, comes in part from wells, but in the main is derived from Frazer Creek, which is a small stream rising in the Olympic foothills back of the town and flowing through the town site. About one-half of the water of the stream is taken out in pipes and distributed by gravity. As the water is often subject to contamination, and is of insufficient quantity for the future, it affords a somewhat unsatisfactory supply. A plan is on foot to secure water from Little River, which is within 6 miles of the city. This stream rises in the snow fields of the Olympic Mountains and carries a large volume of excellent water. The wells that have been dug about Port Angeles vary in depth from 12 to 40 feet. The water-bearing strata of sand and gravel are overlain by clay, which prevents contamination from the surface. The water level is lowered somewhat in the summer months, but for domestic uses the wells are never exhausted.

Port Crescent, located on the Strait of Juan de Fuca, a few miles west of Port Angeles, secures its water supply mainly from wells, but to a limited extent from a small lake. The wells range in depth from 16 to 20 feet. Water is obtained from sandstone, which is overlain by a thin layer of soil. The water rises in the wells to within a few few feet of the surface, and the level is scarcely affected by pumping.

CLARKE COUNTY.

General statement.—Clarke County is situated on the southwestern border line of the State, having Columbia River on its southern and western sides, Cowlitz County on the north, and Skamania County on the east. From a low plain along the Columbia the surface rises gradually to the foothills of the Cascades until the northeastern part of the county is reached, which presents a very broken appearance. The principal streams are the North and South forks of Lewis River, Salmon River, and Washougal River.

The yearly rainfall of Clarke County varies in passing from west to east, but it may be said to average about 50 inches. The precipitation is nearly all in the form of rain, the elevation above sea not being sufficient to produce snow to any marked degree.

The bed rock is mainly basalt, except in the northeastern portion of the county, where the metamorphic and granitic rocks of the Cascades prevail. The weathered basalt affords an excellent soil, and agriculture has come to be a very important industry. The soil has formed to such a depth that it contains a good water supply, and surface wells are therefore in common use. Along Columbia River are broad gravel terraces from which large quantities of water are obtained by means of springs and wells. The springs are common along the terrace bases and often yield large amounts of water. The wells are from 25 to 75 feet in depth, and the water-bearing strata are usually overlain by clay, so that surface contamination is at a minimum.

Municipal systems.—Vancouver, the county seat, secures its water supply from 3 springs and 2 wells. The amount thus obtained is sufficient for present needs, and doubtless will be ample for some time to come. There are no sources of contamination, and the water is of excellent quality. A gravity system of waterworks is used. The wells about Vancouver range in depth from 30 to 75 feet. The water is found in a stratum of coarse gravel, which is overlain by clay. It rises to within 25 feet of the surface, and very little change in the level is noted from season to season. The water level is affected only to a slight degree by pumping. Besides its use for domestic purposes, the water system is drawn upon for fire protection, boiler supply, etc. An analysis of the water showed the total solids per gallon of water to be 10.05; organic matter per gallon, 0.60; hardness, 11.30.

Springs.—Five miles east of Vancouver are 3 springs owned by the Vancouver Waterworks Company. The water flows out in streams from a bed of gravel which outcrops upon a hillside. The flow varies slightly at different times, but is about 1,750,000 gallons daily. The water is soft, has a pleasant taste, and carries no sediment.

COLUMBIA COUNTY.

General statement.—Columbia County lies between Wallawalla County, on the west, and Garfield County, on the east, and reaches from the Oregon line northward to Snake River. The southern part of the county lies within the broad plateau of the Blue Mountains, and has a height of from 4,000 to 5,000 feet above the sea. The northern part is a region of high, rolling hills and deep ravines. Along the northern border Snake River flows in a canyon that has a depth of 1,000 to 1,500 feet.

The rainfall varies from 15 inches a year along Snake River to 25 inches in the central and southern parts. In the Blue Mountains it is sufficient to produce a forest covering. In the northern part of the county the bunch grass which once grew so luxuriantly is fast giving way to wheat fields. In agriculture irrigation is necessary only along the benches or terraces of the Snake, where there are many fine fruit and alfalfa ranches.

As far as known, there are no other rocks in the county save basalt. Some parts of the basalt are very vesicular or porous, and are commonly water bearing. In digging wells an ample supply of good water is generally found within 50 feet of the surface. On the hillsides, wherever the porous basalt outcrops, springs may occur, and they are in common use as domestic water supplies.

Municipal systems.—Dayton, the principal town and the county seat of Columbia County, obtains its water supply from springs. These afford a supply which will doubtless be ample for all time to come. A gravity system of waterworks is used. In a few instances water is obtained from private wells, which range in depth from 25 to 50 feet. The water is found in very porous layers of basalt. In the wells the water level varies slightly with the seasons, but is not affected to any appreciable extent by pumping.

Springs.—Near Dayton are the springs from which the city water supply is derived. The water seeps out from beds of gravel at the base of a hill. The amount of water varies considerably with the season, the flow being reduced in the dry summer months. The water is soft, and no deposits of mineral matter or sediments are found about the springs.

COWLITZ COUNTY.

General statement.—Cowlitz County is situated on the southwestern boundary of the State, north of Clarke County and Columbia River.

The western half of the county is composed of low irregular hills and broad stream valleys; the eastern half is very rough and broken, since it contains the foothills and outlying spurs of the Cascades. The principal streams are Cowlitz, Toutle, and Kalama rivers.

The annual rainfall varies from 65 inches on the western margin to 60 inches in the eastern part. Every part of the county is therefore well watered and heavily forested. There is sufficient water in the streams to supply any possible municipal demands. On the terraces or benches of the larger streams good water is secured from wells at depths between 15 and 50 feet.

In the northern and western parts of the county the prevailing rocks are shales and sandstones of Eocene age. Along Cowlitz River these rocks are coal bearing, and in the neighborhood of Castle Rock and Kelso coal mines have been in operation for some time. The soft coal measures have readily decomposed at the surface, and upon them is a residual soil many feet in thickness. From the soil or the porous rock below water in large quantities is readily obtained by wells of moderate depth. In the southeastern part of the county, in the vicinity of Kalama, the usual rock is basalt, and from it water is secured in wells averaging 25 feet in depth.

Municipal systems.—Castle Rock obtains its water supply from a stream which rises in the foothills east of the town. This supply is sufficient for the present, but must be supplemented in the future by water from some other source. The water is brought from the stream in pipes and distributed by a gravity system. The wells in the vicinity of Castle Rock vary in depth from 15 to 20 feet. The water-bearing material is gravel. The height of the water column depends upon the stage of water in Cowlitz River near by, rising and falling with the river level.

Kalama obtains its water by a gravity system from two creeks. The supply will doubtless have to be increased in the future. The water is very good, the only contamination being from a small amount of decaying vegetation. A few wells are used about Kalama, having an average depth of 25 feet. They are sunk in basalt and, as contamination may be entirely prevented, the water is very good.

DOUGLAS COUNTY.

General statement.—Douglas County is situated immediately east of the central part of the State, within what is commonly known as the "Big Bend" of the Columbia. Its surface is that of a plateau, broken by the Badger Mountains in the western part and by the Saddle Mountains in the southern part, and sloping gently from north to south. Along its northern margin the plateau has an elevation of about 3,000 feet above sea level, which decreases to less than 1,000 feet along the southern border of the county. Within the plateau are three notable canyons or deep clefts, namely, the present valley of the Columbia, and Moses and Grand coulees, the latter doubtless representing a former course of Columbia River. Several small creeks which enter Moses Coulee sink in the sand and do not form a main stream. In Grand Coulee is a chain of lakes, the largest being Blue and Moses lakes. Some of the lakes are fresh, but the majority are alkaline.

Douglas County lies within the region of lowest rainfall in the State. In the northwestern part the average precipitation for the year is 15 inches; in the remainder of the county it is 10 inches or less. The precipitation is largely in the form of snow, especially where the elevation is greatest. There is no forest growth, and prairie conditions wholly prevail. In the highest portions of the county the bunch grass grows abundantly, and cattle raising is an important industry. Here also wheat may be grown successfully, and it has already come to be an important product. In the southern part of the county, where the rainfall is least, irrigation must be practiced in order to carry on agriculture.

The bed rock is practically all basalt except a narrow fringe of granite which is exposed in the canyon walls of the Columbia, and some granite outcrops in the northern end of Grand Coulee. A small area of early Tertiary sandstone underlies the basalt along Columbia River opposite Wenatchee, and late Tertiary lake beds covering a considerable area of the basalt in the southern part of the county should also be noted. From the basalt a very thick and fine-grained soil has been formed, which retains water to an unusual degree. In this way enough water is held within the soil after the winter precipitation to grow and mature the wheat during the coming spring and summer. Within the soil or the porous portions of the basalt below it is usually not difficult to secure a sufficient supply of water for house and farm purposes. Springs are more or less common throughout the county, more particularly at the bases of the cliffs along the Columbia and the coulees. Springs are largely the sources of the lakes mentioned above.

Municipal systems.—The town of Wilsoncreek depends in the main upon wells for its supply of water, but a small stream is also used to some extent. The supply is barely sufficient for present needs, and another source must be sought in the future. While some of the wells have soft water, the others are slightly alkaline. They range in depth from 12 to 54 feet. The more shallow wells obtain water from beds of gravel, while the deeper wells enter the bed rock. The water level in the wells scarcely varies from season to season and is not ordinarily affected by pumping.

Grand Coulee, which has a northeast-southwest direction across the county, was in a former time occupied by Columbia River. Along the course of the coulee there is now a chain of shallow lakes, some of which are fresh, but the most of them are alkaline. The following descriptive matter concerning two of them is taken from Vol. I, of the Annual Report, Washington Geological Survey, for 1901.

Moses Lake, which lies about 12 miles southeast of Ephrata, on the Great Northern Railway, is about 18 miles long and a mile wide, and is very shallow. The average depth is approximately 20 feet. It lies in a shallow basin with low banks, so that a rise of but a few feet would inundate a large section of country. The water is unfit for drinking purposes, but is not strongly alkaline and could probably be used in irrigation. The section of country in which these lakes are located is of course very dry, and supports only a scanty vegetation. Where there is water, however, the soil is very fertile. The lake drains a large area through upper Crab Creek. It has no outlet, but across its foot lies a low range of sand hills through which the water seeps into the sources of lower Crab Creek, which occupies the bed of the canyon below. Along this canyon lie numerous shallow ponds which dry up in summer. The deposits left by these are not of any considerable value, though they contain an appreciable quantity of borax.

An interesting feature of Moses Lake is the fact that it is gradually rising, having risen about 10 feet in the last seven years. If it continues to rise through a few more feet it will break through a clear course into lower Crab Creek and empty into the Columbia.

The analysis of the water of Moses Lake is as follows. The analysis is by H. G. Knight:

[Parts per thousand.]

Total solids	0.32357
Volatile solids	.10095
Nonvolatile solids	.22262
Silica	.01502
Alumina and iron oxide	.00331
Calcium carbonate	.06235
Magnesium carbonate	.07525
Sodium sulphate	.01258
Sodium chloride	.01895
Sodium carbonate	.10914

More interesting is the so-called Soap Lake, or Sanitarium Lake, situated about 6 miles north of Ephrata. This lake is so called because it is so strongly alkaline as to be soapy to the touch, and when a strong wind blows across it the water along the shore is beaten into great rolls of foam. Fish can not live in the water, nor is there any vegetation in this as in Moses Lake. The water is used for bathing, but to those not accustomed to its use the water has a slightly caustic or irritating effect. It is also claimed that it is useful medicinally. There is much of peculiar interest about the lake. It is about 2½ by three-fourths miles in extent and is very deep in places and probably averages about 40 feet. It drains only a very small area of country and has neither inlet nor outlet in the form of streams. It is located in a deep basin walled to the height of 100 feet or more on the east and west by cliffs of black basalt. The land to the north and south rises slowly; on the south to nearly the height of the cliffs, but on the north the rise is so slight that should the lake rise 15 feet it would empty into the next of the chain of lakes to the north. The source of the water of the lake is said to be a spring in the center. The Indians of the neighborhood assert that only a few years since the lake was very small and was fed by this strongly alkaline spring. Fresh water is, however, continually seeping in from the shores, as is shown by the fact that fresh-water wells may be sunk even but a few feet from the shore, and that the cattle, disliking the strongly alkaline water, face the shore to obtain the sweeter seepage.

The analysis of the water is as follows:

[Parts per thousand.]

Total solids	28.2669
Volatile solids	.62503
Nonvolatile solids	27.64186
Silica	.12816
Alumina and iron oxide	Trace.
Calcium sulphate	Trace.
Calcium carbonate	Trace.
Magnesium sulphate	.39099
Sodium sulphate	6.34872
Sodium chloride	5.81384
Sodium carbonate	14.08901
Potassium carbonate	.51177
Lithium sulphate	Trace.
Phosphorus pentoxide	.12018
Carbon dioxide (semicombined)	1.37034
Borax	None.
Iodine	None.
Free ammonia	.03400
Albuminoid ammonia	1.1060
The specific gravity	1.0260

FRANKLIN COUNTY.

General statement.—Franklin County lies between Wallawalla County on the south and Adams County on the north, with Columbia River as its western boundary. The surface is that of a plain, sloping gently toward Columbia and Snake rivers. In the northwest corner of the county the plain is about 300 feet above the surface of the Columbia, giving rise to the cliffs along the stream known as the White Bluffs. In the eastern part of the county the plain rises to a height of 300 to 400 feet above the level of the Snake. Near the confluence of the two rivers the plain decreases in elevation and the banks of the streams are but a few feet in height.

The average rainfall is about 10 inches a year. This will not admit of any forest growth and scarcely permits of the growth of bunch grass. Agriculture may be carried on only where irrigation is possible. Irrigated tracts along the rivers yield very fine returns in alfalfa and fruit.

In the western part of Franklin County the outcropping rocks are thin beds of sand and clay, with layers of volcanic dust, which represent Miocene lacustrine sediments. Such deposits at one time may have covered the entire county, but in the eastern portion basalt alone now appears. At a number of places successful wells have been drilled in the basalt, the water being found in the more porous or vesicular parts of the rock. The depth of the wells varies from about 200 to nearly 700 feet. It is evident that, in advance of drilling, the depth at which water will be found is conjectural. In the western part of the county a well is now being drilled in the sedimentary rocks noted above.

Deep wells.—W. T. Braden, living at Connell, completed a deep well in September, 1902. The well is located in a canyon, and its mouth has an elevation above the sea of 840 feet. It has a diameter of 5 inches and a depth of 676 feet. The well is cased from the surface to solid rock, a distance of 100 feet. The water rises in the well about 36 feet and is brought to the surface by a wind pump. The temperature of the water when brought to the well mouth is 51° F. The water level does not vary during the day or year and is not affected by pumping. The cost of the well, including the pumping machinery, was about $3,000.

There are several firms making a business of drilling wells in Franklin County, the most prominent of which is the Reinbolt Well Drilling Company. A few of the wells drilled by this company, with their depths, are here given: H. W. Brummond, 410 feet; John Finkbiner, 485 feet; John L. Wordheim, 212 feet; Connell Land and Improvement Company, 243 feet; William Fisch, 265 feet; William Elgin, 323 feet; Charles Schelley, 487 feet.

Springs.—A number of springs are known to exist in the eastern part of Franklin County, although but a few of these have been reported. These springs are oftentimes the sources of supply for small lakes which have no outlets.

JEFFERSON COUNTY.

General statement.—Jefferson County is situated in the northwestern part of the State, between Clallam County on the north and west and Chehalis and Mason counties on the south, and extends from Puget Sound to the Pacific Ocean. Topographically the surface presents a great diversity. The county contains the most rugged portions of the Olympic Mountains, the only areas that are comparatively level being in the northeastern part, within a few miles of the shores of Puget Sound. This is the only part of the county inhabited to any degree, there being no inhabitants within the Olympics and but very few west of the mountains along the Pacific coast.

The rainfall along the western coast averages over 85 inches a year. It decreases steadily eastward and is less than 20 inches in the vicinity of Port Townsend. The district east of the Olympics has a low rainfall because the high mountains divert to some degree the rain-laden westerly winds. Within the Olympics are several glaciers and snow fields which feed the streams during the rainless months of summer.

The band of Tertiary rocks which encircles the Olympic Mountains outcrops in both the eastern and the western parts of the county. The rock series is composed chiefly of conglomerates, sandstones, and shales, and without doubt contains large quantities of water which can be secured by means of wells. The bed rock just mentioned is often deeply buried by glacial sediments, which are important reservoirs.

Municipal systems.—Port Townsend obtains its water supply from driven and dug wells owned by the Spring Valley Water Company. From these wells 250,000 gallons per day are obtained by pumping. This supply is hardly sufficient for present needs, and a gravity system from some stream coming out of the Olympic Mountains is in contemplation. The water in use at present is of good quality. The wells do not enter bed rock, the water-bearing materials being sand and gravel. A heavy bed of clay which lies above the sand and gravel prevents contamination. An analysis of the Port Townsend water is given below:

Analysis of water from Port Townsend, Wash.

[Grains per gallon.]

Silica	1.255
Alumina and iron oxide	.146
Calcium carbonate	16.731
Magnesium carbonate	6.987
Magnesium chloride	11.200
Calcium sulphate	1.826
Sodium and potassium chlorides	29.236
Sodium and potassium carbonates	1.531
Total solids	68.912

Port Ludlow obtains its water supply from a small creek. The water is soft, of good quality, and sufficient for all probable future needs. A gravity system of waterworks is used. The water is drawn upon for a boiler supply for the Port Ludlow mills as well as the domestic supply for the town.

KING COUNTY.

General statement.—King County is situated west of the center of the State and extends from the summit of the Cascades westward to Puget Sound. It lies between Snohomish County on the north and Pierce County on the south. Along the shores of the sound the surface is that of a plain, rising to a height of about 300 feet above the sea; east of the plain are hills and ridges, the latter having in general a north-south direction; immediately east of this belt are the mountains, rising from a height of about 3,000 feet along their western border to an average height of 6,000 feet, when the summit line is reached. The mountains are deeply dissected by the several forks of Snoqualmie, Cedar, Green, White, and other rivers.

The annual rainfall varies from 40 inches along the shores of the sound to more than 60 inches within the mountains. About the sound practically all of the precipitation is in the form of rain, but with increase in elevation the snowfall becomes important, and in the higher mountains the amount of snow falling each year is very large.

The presence of snow and glaciers has an important bearing on the run-off of the streams from season to season. Apart from its value as sources of municipal supply, the movement of so much water from higher to lower levels is productive of great power. Already the water power of the cataracts and falls is being harnessed for the use of man. At Snoqualmie Falls, 25 miles east of Seattle, a plant has been installed which develops a total of 10,000 horsepower. Snoqualmie River at this point has a vertical drop of 270 feet, with a flow of about 1,000 second-feet during the driest season and about ten times as much during the periods of high water.

The strata which outcrop about the sound and eastward for a distance of about 25 miles are mainly clastic rocks of early Tertiary age. At many places they are coal bearing, and important coal mines have been developed at Black Diamond, Franklin, Palmer, Renton, Newcastle, Issaquah, and elsewhere. East of the Tertiary sediments are the metamorphic and igneous rocks of the Cascades, which in King County at least are virtually unstudied. In the vicinity of the sound bed rock outcrops but rarely, being covered by a heavy mantle of glacial sediments. At many places this mantle is known to be more than 500 feet in thickness. The glacial sediments comprise beds of till, with stratified sand, gravel, and clay. From the layers of sand and gravel which are interstratified with the till an abundant supply of good water is generally obtained. The wells are usually shallow, it being rarely necessary to go deeper than 40 feet. Springs are very common about the bases of the hills or upon the hillsides where the water-bearing gravels and sands outcrop.

Municipal systems.—The town of Auburn obtains its water supply chiefly from wells, which vary in depth from 40 to 50 feet. The wells are sunk in the alluvium of the White River Valley, the water-bearing materials being sand and gravel. In no instance has bed rock been reached. In some instances shallow wells have been used for a little time, but in these the water is not good. The water from the deeper wells is soft, is not contaminated, and is obtained in ample quantity, in some instances rising to the surface. No other supply of water for drinking purposes is contemplated, but it is likely that water for fire protection will be obtained from White River.

The city of Ballard obtains about 300,000 gallons of water daily from springs and deep wells, about half from each source. The wells are the more satisfactory. While this amount is ample for present needs, it will not be sufficient in the course of time if the city continues its rapid growth. It is very likely that in the near future the supply for Ballard will be secured from the Cedar River system owned by the city of Seattle. The surface wells in Ballard have depths of 12 to 20 feet, but the wells used for the municipal supply average about 160 feet in depth. For the most part they penetrate glacial till or hardpan, the water-bearing strata being beds of sand and gravel. The system of waterworks is direct pressure.

A sanitary analysis of water from one of the deep wells in Ballard, made by Prof. H. G. Byers, of the University of Washington, is as follows:

Sanitary analysis of water from deep well at Ballard.

[Parts per million.]

Total solids	165.66
Oxygen consumed	2.89
Chlorine	5.50
Nitrogen as free ammonia	.874
Nitrogen as albuminoid ammonia	.100
Nitrogen as nitrites	None.
Nitrogen as nitrates	.320

The municipal supply of water for Columbia City is obtained from Seattle. A few private wells are in use having an average depth of 30 feet. They penetrate glacial deposits only and from them water of good quality is obtained.

Water for the town of Enumclaw is furnished from the system of the White River Lumber Company. The water comes from streams flowing out from the Cascade Mountains, and as there are no sources of contamination it is of excellent quality. A gravity system of waterworks has been installed. It is possible that in the future the town supply may be taken from some springs located about 4 miles away. The springs are at a height of about 270 feet above that of the town. A few wells are in use about Enumclaw, which have an average depth of 30 feet. The wells are dug in glacial sediments, a till or hardpan lying above, with sand and gravel below. The wells afford excellent water, the flow rising to the surface in the wet season.

The water supply for Issaquah is furnished by the Gilman Water Company, which owns large springs near the town. The water is of good quality, there being no sources of contamination except possibly a little decaying vegetable matter. The water is conducted through the town by a gravity system. The few private wells in Issaquah range in depth from 20 to 30 feet, the water coming from a stratum of loose gravel. A large quantity of water may be obtained in this way, since it rises almost to the surface and is not affected by pumping. North of the town, toward Lake Sammamish, wells from 60 to 90 feet in depth have been driven, from which there is a continuous flow. The water rises from 3 to 10 feet above the surface.

The town of Kent gets its supply from springs which yield water of excellent quality. While the springs now drawn upon afford a supply for present needs, the product of other springs near by will be drawn upon in the future. From the springs the water is carried throughout the town by a gravity system. In the region about Kent good water may be obtained by means of driven wells. The wells when driven to a depth of 200 feet are artesian in character, the water rising about 6 feet above the surface.

Water for Renton is obtained from a spring situated near the town limits and at a height of 320 feet above the level of the town. The spring belongs to the Seattle Electric Company, but the town has a lease upon it for fifty years. The spring supplies 120,000 gallons of water daily, and should this not be sufficient for future needs water may be obtained from other springs or from Cedar River, which flows through the town. The water, besides being used for domestic purposes, affords fire protection and furnishes the necessary boiler supply for a coal mine and a brickyard. The private wells in use in Renton are mostly shallow, ranging in depth from 10 to 25 feet. Only one enters rock, the others obtaining water chiefly from the gravels of the Cedar River flood plain.

The city of Seattle obtains its supply of water from Cedar River and Cedar Lake. The source of supply is in the Cascade Mountains, the water coming to the reservoir directly from the snow fields. The water is, therefore, soft, clear, and of superior quality. The city owns Cedar Lake and a large portion of Cedar River. The available water supply averages about 600,000,000 gallons per day. There are now piped to the city 22,500,000 gallons daily. Other supply mains will be constructed whenever they are found to be necessary.

A sanitary analysis of the city water of Seattle, made by Prof. H. G. Byers, of the University of Washington, on April 27, 1901, gave the following results:

Sanitary analysis of city water of Seattle.

[Parts per million.]

Total solids	36.49
Oxygen consumed	1.26
Chlorine	1.50
Nitrogen as free ammonia	.008
Nitrogen as albuminoid ammonia	Trace.
Nitrogen as nitrites	None.
Nitrogen as nitrates	None.

West Seattle obtains water from private wells and from some springs owned by the West Seattle Land and Improvement Company. The water is pumped into tanks, from which it is distributed by gravity. The supply even at the present time can hardly be said to be sufficient, and it is likely that arrangements will soon be made whereby water may be obtained from the Seattle system. The wells about West Seattle range in depth from 30 to 75 feet, water being most commonly found at about 50 feet. The wells are dug entirely in glacial material, mostly sand and gravel.

Springs.—Near the town of Berlin, in the northeastern part of the county, there is a mineral spring owned by the Everett Bottling Works. The water flows out as a stream from the base of a mountain of granitic rock. The flow is uniform from season to season. The quantity flowing has never been measured. The water has a taste of soda. No improvements of any character have been made at the spring, and so far no use has been made of the water. It is probable that in the near future a hotel will be built at the spring and other improvements made.

An analysis of water from the Berlin springs, made by H. G. Knight, of the University of Washington, is as follows:

Analysis of water from Berlin springs.

[Parts per thousand.]

Solids, nonvolatile	0.5473
Silica	.0078
Alumina and iron oxide	.0150
Calcium sulphate	.0529
Calcium carbonate	.5627
Magnesium chloride	.1693
Magnesium sulphate	.0935
Sodium sulphate	.9331
Potassium chloride	.0267
Carbon dioxide	1.4720

Near the town of Issaquah, at the head of a short, deep valley, is a large spring from which the water supply for the town of Issaquah is taken. The flow has not been measured, but there is sufficient water for a town of 1,000 inhabitants. The water is very clear, cold, and has a pleasant taste. It issues as a stream from a bed of gravel. No improvements have been made at the spring, and none are contemplated. The spring is owned by the Gilman Water Company.

Along the valley side, at the base of a steep hill near Kent, is a large spring from which the town supply of water is largely taken. The daily flow varies from 500,000 gallons in winter to 350,000 gallons in summer. The water is not appreciably charged with minerals, and is very clear and cold when it leaves the spring. It issues as a stream from a bed of gravel which is a part of the glacial sediments. At the spring a reservoir is now being built for storage purposes.

The Great Northern Hot Springs are located near Madison, in the northeast corner of the county. Near the Great Northern Railway, a mile from the springs, the Hot Springs Hotel has been built, with accommodations for 50 guests. The water is piped to the hotel, where it is used for drinking purposes and for baths. The water has been found to be very helpful for rheumatism and for kidney diseases. The water seeps out from the talus rock, and has a temperature of 122° F.

The following analysis of water from the Great Northern Hot Springs was made by C. Osseward, chemist for the Stewart & Holmes Drug Company, Seattle:

Analysis of water from the Great Northern Hot Springs.

[Grains per gallon.]

Total solids	9.9
Chlorine	.87
Iron	.76
Lime	2.33
Magnesia	1.1
Silica	1.34
Sodium	1.63
Potassium	.34
Sulphuric anhydride	.52
Ammonia	.00058

On a hillside near Renton there is a spring issuing from a bed of gravel. The flow is about 120,000 gallons daily. The quantity varies with the season, being about one-fourth less in a very dry season than in a wet one. The water does not carry any sediment, is very clear, and has a pleasant taste. It is used as a town supply by Renton.

KITSAP COUNTY.

General statement.—Kitsap County is situated east of Jefferson and Mason counties, west of King County, and north of Pierce County. It is almost surrounded by the arms or inlets of Puget Sound. With the exception of a range of hills in the southwestern part of the county, along Hood Canal, the surface is that of a plain lying but little above the sea. The coast line is very deeply indented and irregular, abounding in fine bays and harbors.

The rainfall gradually decreases from 60 inches per year in the southwestern part to 30 inches in the northeastern part. It is sufficient to give rise to the very many small streams which are to be found throughout the county and also to produce a very dense forest growth.

Over the major portion of Kitsap County the mantle of glacial sediments is very heavy, so that the bed rock does not often appear at the surface. The wells for the most part penetrate the glacial materials only, and from the latter a satisfactory supply of good water is obtained. As elsewhere within the glaciated area, springs are very common and are often utilized.

Municipal systems.—Bremerton obtains its water supply to a limited degree from wells, but for the most part from a stream which is fed by springs. In this way is obtained a supply of very good water, which is free from any contamination. The quantity will be ample for a long time to come. Gravity is the system employed. The private wells, as a rule, are shallow and are sunk altogether in glacial till, the water flowing from intercalated beds of sand and gravel.

An analysis of water from a spring near Bremerton, made by H. G. Knight, of the University of Washington, is as follows:

Analysis of water from spring near Bremerton.

[Parts per thousand.]

Nonvolatile solids	0.45194
Silica	.01334
Alumina and iron oxides	.04764
Calcium sulphate	.046385
Magnesium chloride	.04008
Magnesium sulphate	.07790
Sodium sulphate	.23686
Lithium sulphate	.02128

The source of supply for Charleston is found in some springs and creeks west and south of the town. From these the water is carried to the town in wooden pipes. It is of good quality, and a quantity ample for present and future needs is easily obtained. The private wells about Charleston range in depth from 20 to 150 feet. These wells have been put down in glacial sediments and the water level rises and falls with the tide in the inlet near by.

The water supply for Port Blakeley comes primarily from a stream in the adjoining hills. A reservoir has been made, and from this, by means of gravity, the water is conducted to the town. There is a certain amount of decaying vegetable matter in the reservoir, and this causes some contamination of the water; otherwise the water is good, and sufficient in quantity to serve the town probably for a long time in the future. Besides this method of obtaining water, cisterns and wells are used to a small degree. These wells have a depth ordinarily of about 70 feet. Most of them are wholly in the glacial till, but some of them penetrate rock altogether, the water-bearing stratum in the latter case being a conglomerate.

Some small streams near Port Gamble are drawn upon for the water supply of that town. From reservoirs along these streams the water is distributed to the town by a gravity system. About 150,000 gallons of water are obtained daily, an amount sufficient for the present and the future. The water is soft and of good quality, no sources of contamination being present. Besides its use for domestic purposes, it is employed to a large extent as a boiler supply.

KITTITAS COUNTY.

General statement.—Kittitas County lies near the center of the State, between Chelan County on the north and Yakima County on the south, and extends from the summit of the Cascades eastward to

Columbia River. From the Cascade divide, which has a general height of about 6,000 feet above the sea, the country descends southeastward to a minimum elevation of 500 feet. In the northwestern part of the county the surface exhibits the usual ruggedness of the higher and wilder parts of the Cascades. The highest peak here, Mount Stuart, has an elevation of 9,470 feet.

The rainfall in Kittitas County varies widely because of the great difference in elevation from point to point. In the high mountains the precipitation is from 50 to 60 inches a year. It decreases eastward until it becomes less than 15 inches at Ellensburg and less than 10 inches in the vicinity of Columbia River. Naturally, the character of the vegetation is greatly modified by the wide variation in the amount of rainfall. The higher mountains as a rule are heavily forested, while the plateaus are sparsely covered with trees. In lower altitudes the trees give way to the bunch grass, which is in turn superseded by sagebrush on the still lower levels. The abundant rainfall of the mountains gives rise to many fine streams, which afford water alike for the use of cities on the plains below and for the irrigation of orchards and alfalfa fields.

The southeastern part of the county is largely covered by Miocene basalts. In the neighborhood of Ellensburg are remnants of a sandstone formation which represents the sediments of a middle Tertiary lake of unknown extent. The geology is somewhat complex, as both sedimentary and volcanic rocks of Eocene and Miocene age are found. The sedimentary beds are lacustrine, and consist chiefly of sandstone and shale. In one of the Eocene sedimentary formations round about the towns of Roslyn and Clealum, seams of coal of great economic value have been found, and here are the largest coal mines in the State. In the vicinity of Mount Stuart, near the southern border line of the county, there are large areas of pre-Tertiary rocks of a complex nature geologically, in which there are granites, granodiorites, serpentines, slates, and schists.

Municipal systems.—The water supply for Clealum comes from mountain springs about 3 miles southwest of town. The springs are 180 feet above the town, thus giving a good head and making it easy to distribute the water throughout the town by a gravity system. For the first mile from the springs a 10-inch pipe was laid, for the next mile an 8-inch pipe, and for the third mile a 6-inch pipe. The water pressure in the town is from 90 to 100 pounds per square inch. The amount of water obtained is believed to be ample for a city of 20,000 inhabitants. Should this supply ever fail, water in great abundance may be obtained from Yakima River, a clear mountain stream which flows through a part of the town. Clealum owns 160 acres of land about the springs, thus effectually preventing contamination. Some time ago an effort was made to obtain artesian water. A well was drilled in Clealum to a depth of 800 feet without striking water. The water supply of the town is used for irrigating as well as domestic purposes.

Ellensburg obtains water from streams which flow out from the foothills of the Cascades. The water obtained in this way, however, is not of the best quality and is barely sufficient for present needs. An unusual demand is made upon the supply, for a large amount of water is used for irrigation as well as for domestic purposes. The private wells which are in use range in depth from 10 to 20 feet. They are essentially surface wells, not entering the rock at all, but obtaining water from beds of gravel. The well water, as a rule, is hard and contains alkali. The water level in the wells varies, the water rising to the surface when the soil is thoroughly saturated as the result of excessive irrigation.

For its town supply Roslyn obtains water from Clealum River, a mountain stream yielding water of excellent quality. This supply is so satisfactory that no dependence is placed upon wells, cisterns, or other sources.

KLICKITAT COUNTY.

General statement.—Klickitat County is situated on the southern border of the State, with Columbia River on the south, Yakima County on the north, and Skamania County on the west. The western part of the county is within the Cascades, and is therefore very rugged. The topography of the central part is that of a broad plateau sloping from the north toward Columbia River. The topography of the eastern end of the county is that of a plain rising but little above the level of the river.

In the western portion of the county the annual rainfall is from 30 to 35 inches, in the vicinity of Goldendale it is 15 or 20 inches, while in the eastern end of the county it is only about 10 inches. As a consequence of the unequal distribution of rainfall, the western portion of the county is a region of forests and streams; the central part has a very sparse forest growth and few streams, but at the same time is one of the best wheat-growing districts in the State; and the eastern part is treeless and virtually without streams, so that agriculture can be carried on only by means of irrigation.

With the possible exception of the extreme western end, all of the county may be said to be covered by Columbia River lava. The bed rock is basalt. As far as known, no deep wells have been drilled into it, as in other parts of the State, to determine whether or not it is water bearing. That it is water bearing is largely proved by the fact that in a number of places springs issue from the outcrops of porous basaltic rock. The springs in some instances have a temperature considerably above that of the surrounding atmosphere. In some cases also they may be classed as mineral springs, and are believed to have medicinal qualities as well.

Municipal systems.—The water for Goldendale is piped from a spring on the southern slope of Simcoe Mountain, 12 miles to the north. The supply is sufficient for present needs, but will probably have to be increased in the future. Other good springs are conveniently near, and the water from these can be easily utilized. The water is soft and uncontaminated. The spring is located at a sufficient height above the city to give a good head of water. A few wells are used, ranging in depth from 12 to 75 feet. Most of the wells are shallow, water being most commonly found at 20 feet in beds of gravel. From the wells a large amount of water may be obtained. The water level shows but little change from season to season, and is affected by pumping only in a slight degree. In Goldendale a large amount of water is used in irrigation.

Springs.—On Government land in T. 6 N., R. 13 E., there is a large spring, or rather a group of springs. At these springs the water flows out in a stream from basaltic rock. The springs are located at the base of a bluff rising from the valley of Klickitat River. The flow is large, there being no perceptible variation from season to season. The water is clear and odorless, but it has an unpleasant taste. It has a temperature of 76° F. Bubbles of gas are constantly escaping from the water. It has been used to a limited degree for medicinal purposes.

On Big Klickitat River in T. 4 N., R. 14 E., is a spring which is considered to have special medicinal properties. By the internal use of the water, stomach and kidney diseases are benefited, and rheumatism is helped by bathing in the water. The spring issues as a stream from basaltic rock. It has a temperature of 100° F. There is a slight film on its surface and it carries a little sediment. It has a strong mineral taste and is charged with gas, iron, and sulphur. Deposits of iron oxide are made along the stream as it flows away from the spring. It is planned to make a health resort at this spring, and a hotel and bath house are in process of construction. An analysis of the water, made by Prof. H. G. Byers of the University of Washington, is as follows:

Analysis of spring water from near Big Klickitat River.

[Parts per million.]

Total solids	758.7
Nonvolatile solids	569.2
Volatile solids	189.5
Silica	85.5
Ferric oxide and alumina	104.9
Calcium carbonate	129.6

Magnesium carbonate	184.8
Calcium sulphate	4.5
Sodium chloride	10.1
Potassium chloride	22.3
Potassium sulphate	27.5
Free carbon dioxide	700.0

LEWIS COUNTY.

General statement.—Lewis County is in the southwestern part of the State and extends from the summit of the Cascades to Pacific County on the west, with Chehalis, Thurston, and Pierce counties on its northern border, and Wahkiakum, Cowlitz, and Skamania counties on the south. The county has a very diversified topography. The western end of it lies within the Coast Range, where the highest hills or mountains are from 2,000 to 3,000 feet in height. East of the Coast Range is a broad north-south valley which is in reality a part of the Puget Sound basin. East of this great valley rise the mountains of the Cascades, reaching heights of 5,000 or 6,000 feet on the main divide. The mountains have been greatly dissected by the streams, and some of the valleys, notably that of Cowlitz River, are very broad and deep.

The rainfall is heaviest in the western part of the county, where it averages 70 inches per year. It decreases eastward until in the neighborhood of Chehalis and Centralia it is 50 inches. In the mountains of the eastern part of the county the average yearly rainfall is 60 inches. This heavy rainfall gives rise to a very large number of streams and produces a luxuriant forest growth which is equal to any found elsewhere in the State.

The eastern part of the county, or that within the Cascades, is practically unknown geologically. There are a few small areas of coal-bearing sandstones and shales lying along the upper Cowlitz River and in the region about Cowlitz Pass. The geology of the western two-thirds of the county has been studied to some extent, and as far as known the rocks are of Eocene age. Fossils of marine Eocene types occur in great abundance along the Cowlitz in the vicinity of Little Falls. The sedimentary rocks are mainly sandstones and shales and are coal bearing at a number of places, notably about Chehalis and Centralia, in the vicinity of Alpha and Cinebar, and near Morton. Upon the sedimentary rocks in most places a deep soil has formed, and within this water is obtained with ease by means of shallow wells. Springs are common upon the hillsides, and they may be regarded as important sources of good water. The amount of surface water to be had is so very large that it is not probable that recourse to deep wells will ever be necessary. The structure of the sedimentary rocks is such that they undoubtedly contain artesian basins, which may be tapped whenever the need arises.

Municipal systems.—The water for Centralia is obtained partly from wells and partly from Skookumchuck River. From neither of these is very good water obtained, and some other source must be sought out. The wells range in depth from 20 to 30 feet. Water is most commonly found at about 18 feet, in beds of gravel, but as these beds are not overlain by clay or other impervious material, contamination from the surface is not prevented. From these wells a large supply of water may be obtained. The water level varies but little during the year, being somewhat lower in the dry season.

The water supply for Pe Ell is obtained mostly from wells, although a few families derive their supply from springs. The spring water is satisfactory, but the same can hardly be said of the wells. The latter are very shallow and contamination from the surface is very easy. The well water comes from gravel and rises to the surface in some cases. A large supply of water is had, the water level scarcely varying during the year.

LINCOLN COUNTY.

General statement.—Lincoln County is in the eastern part of the State and is bounded on the east by Spokane County, on the west by Douglas County, on the south by Adams County, and on the north by Columbia and Spokane rivers. The surface is that of a plateau having a general height of about 1,500 feet above sea level. On the north the plateau slopes very abruptly to the canyon of the Columbia, while on the south there is a gentle slope toward Crab Creek. Low, rolling hills occur here and there.

The yearly rainfall varies from 10 inches in the western half to 15 inches in the eastern portion. This is too small to permit of forest growth and hence the county was formerly a prairie region clothed with grasses. The bunch grass now, however, has largely given way to wheat fields, and the county produces each year an increasing amount of grain. The streams are in the main of the intermittent type, there being but very few that are of a permanent character. The small streams are active in the runways during the winter and spring months only and disappear with the coming of summer.

With the exception of the outcrops of granite in the vicinity of Columbia and Spokane rivers the bed rock is altogether basalt. The basalt has within it porous layers which become filled with water, thus forming important reservoirs. In the ravines and "coulees" the porous basalt often outcrops and gives origin to springs which afford an ample quantity of water for general house and farm use. As a rule, the springs are active all the year, and in some instances have a flow sufficient for use as a municipal supply. In cases where springs have not been available wells have been dug in the basalt, and whenever the porous rock was encountered ample supplies of water were obtained. Ordinarily the wells vary in depth from 25 to 50 feet.

Municipal systems.—Water for Davenport is obtained from springs near the town. The supply is sufficient for present needs, but it is probable that it will have to be increased. The water is of good quality and there are no sources of contamination. A gravity system of waterworks is used. The wells in the region vary in depth from 20 to 60 feet, the water being most commonly found at 30 feet. The wells enter the rock, and a layer of clay at the surface prevents any contamination from that direction. No flowing wells have been found, but a large supply of water is obtained from the common wells. The water level does not vary during the year and is not affected by pumping. Much water is used in irrigation as well as for domestic purposes.

Harrington obtains its water from wells, although springs are used to some extent. The wells vary in depth from 30 to 100 feet. Water is most commonly found at about 35 feet. All of the wells enter basalt. The water usually rises to within 20 feet of the surface, where it stands constant the year round. It is of good quality, but will doubtless be insufficient for future demands. The water is pumped into a standpipe and distributed by gravity.

The supply for Sprague is obtained in part from a spring and in part from wells. At the spring the water issues from basaltic rock and varies much in quantity from season to season. During the dry season the supply from the spring becomes insufficient and the wells are relied upon. The supply from the wells seems to be inexhaustible and constant pumping makes no impression on the water level. The water from the spring is distributed by gravity, while the well water is obtained by pumping. From these sources excellent water is obtained in quantities believed to be sufficient for all future needs. The private wells of the region vary in depth from 20 to 40 feet. Water is commonly found at a depth of 20 feet. These wells do not enter rock, but are wholly in surface material. The water-bearing materials are sand and gravel. The wells, although shallow, afford a large quantity of water, the level being lowered only in a long, dry season.

Water for Wilbur is obtained from Goose Creek, which has its source in two large springs, and also from some wells. The water is of good quality, and ample in quantity for present and future needs. A gravity system of waterworks has been installed. The wells are all very shallow, the usual depth being about 12 feet. They enter the basaltic rock which underlies the town. Contamination from the surface is prevented by a layer of clay. The wells, although shallow, are relied upon for the domestic supply, and the water from the springs is used largely in irrigation.

Springs.—In sec. 21, T. 25 N., R. 37 E., near the town of Davenport, there is a large spring from which about 360,000 gallons of water flow daily. This supply is fairly constant, although slightly less in summer. The water is clear and cold and has a pleasant taste. It issues as a stream from the rock. It is used as a water supply for the town of Davenport.

Near Davenport, on the farm of J. E Ludy, there is a spring which is located in the bottom of a deep draw or gulch. The water comes out as a stream, and in quantity sufficient to supply about 15 families. It is slightly alkaline, but there are no deposits of mineral matter or sediment about the spring. The water has a temperature of about 45° F.

Near Harrington, in sec. 34, T. 23 N., R. 36 E., there is a spring owned by J. L. Ball. The water issues from the rock at the base of a bluff. It is clear and of a very good quality. It is used for a general farm supply.

L. T. Luper owns 2 springs near Harrington, in secs. 1 and 9, T. 23 N., R. 36 E. The spring in section 1 flows about 23,000 gallons per day, and the one in section 9 about 28,000 gallons per day. Neither spring shows any variation in flow from season to season, and in both the water is clear, of good quality, and apparently not mineral bearing. In each case the water issues as a stream. The water is used as a house supply and in watering stock.

Near Sherman, in sec. 25, T. 29 N., R. 33 E., H. B. Fletcher owns a spring which appears as a stream. The spring is located in a valley. The flow is very large and is constant from season to season. The water as it issues is cold, clear, and of a superior quality. It is used by the farmers for their stock, but it has been proposed to pipe the water to Wilbur as a supply for that town.

MASON COUNTY.

General statement.—Mason County lies in the western part of the State, being separated from the Pacific Ocean by Chehalis County, which borders it on the west. It is bounded on the north and northeast by Jefferson and Kitsap counties, and on the southeast and south by Pierce and Thurston counties. The northwestern portion of the county extends into the Olympic Mountains, and hence is very rugged and broken in character. Most of the remaining part of the county is very hilly, the only portions that are level to any degree being those immediately about Hood Canal and other inlets of Puget Sound. The streams which come from the mountains flow in canyons, and the interstream divides are very sharp.

The yearly rainfall is very heavy, ranging from 85 inches on the western border to 60 inches in the extreme eastern portion. As one result of the copious rainfall there is a heavy forest growth, the forests of Mason County being regarded as among the best in the State. In the southeastern part of the county, the only portion which is settled to any extent, water for domestic purposes is obtained very largely from the glacial deposits, which are here very thick. As a rule the wells are shallow, water being obtained at depths varying from 10 to 25 feet. With the abundant rainfall and the heavy mantle of unconsolidated surface materials it is not surprising that springs are very common. The water issues from the springs in the form of streams, and usually in sufficient quantities to afford town supplies.

Municipal systems.—The water supply for Shelton, a town of about 1,000 people, is obtained from some large springs, and will doubtless prove inadequate when the population of the town is doubled, but there are other large springs located conveniently near which may be utilized. The water is soft and pure and very satisfactory for domestic purposes. A gravity system of waterworks is used. In the region about Shelton there are a good many wells from which excellent water is obtained. In some instances the water rises to the surface, and the water level is not distinctly lowered except in September, the month of the least rainfall. The wells are as a rule driven wells, the materials penetrated being glacial till, sand, and gravel. The wells are shallow, varying from 10 to 25 feet in depth. The water-bearing material is overlain by hardpan, so that there is no contamination from the surface.

Springs.—As noted above, the town of Shelton obtains its water supply from two springs located in sec. 12, T. 20 N., R. 4 W. The flow has not been measured, but it is ample for all present demands. The springs issue as streams from gravel beds which outcrop on a hillside above the town. The water contains a small amount of iron, but there are no deposits of mineral matter about the springs.

At other places about Shelton, notably in sec. 18, T. 20 N., R. 3 W., and in sec. 13, T. 20 N., R. 4 W., are other springs which supply large quantities of water. They issue from gravel beds at the base of a bluff about 150 feet high. From the top of the bluff a gravel terrace extends for several miles. Lying upon this terrace, near the springs, there are several lakes, and it has been suggested that the lakes are the sources of the spring water.

OKANOGAN COUNTY.

General statement.—Okanogan County extends from the British Columbia line to Columbia River, and from Ferry County on the east to Chelan and Whatcom counties on the west. This large county presents a great diversity of surface, and within it are rugged mountains, rolling hills, and broad plateaus which merge into plains. The western portion of the county is a region of high mountains and deep valleys. Between Methow and Okanogan rivers is a bold mountain ridge which has a north-south course. Along the eastern border line of the county there is likewise a mountain ridge, with a north-south course and a general height of about 4,000 feet above the sea. Along the southern border of the county the Columbia flows in a deep canyon, but the Okanogan, its chief tributary, is a meandering stream flowing in a broad and comparatively shallow valley. The Methow Valley is likewise very broad and open, except for the last few miles of its course, when it assumes a canyon aspect.

The rainfall of Okanogan County is light in comparison with other parts of Washington. In the mountainous area the annual precipitation is from 15 to 20 inches. Over much of the remaining part of the county it ranges from 10 to 15 inches, and over a small portion it is even less than 10 inches. The forest grows exclusively upon the highlands, chiefly in the Cascades, in the mountains along the eastern border, and on the mountain ridge between Okanogan and Methow rivers. Over those parts of the county where the trees can not grow bunch grass abounds, only the lowest plains along Okanogan River being given over to sagebrush. From the mountains good streams of water flow to the plains and make possible irrigation on a large scale in the valleys of Methow, Okanogan, and Columbia rivers.

As far as known the rocks of Okanogan County are chiefly gneisses, schists, slates, and crystalline limestones. Here and there are small remnants of more or less extensive sediments of Tertiary lakes. Over large areas intrusive and extrusive igneous rocks of various kinds prevail. Over much of the surface there is a thick mantle of soil, and within this in most places water may be obtained by means of wells. Springs commonly occur, and they are relied upon to a large degree by the settlers. Surface water is usually sufficiently abundant to supply the herds of cattle and sheep with their requirements.

Municipal systems.—Loomis obtains its water from Sinlahekin Creek and from a spring owned by J. M. Judd. Neither source is very satisfactory, and it is planned to secure a supply from Toats Coulee Creek, a mountain stream of pure water which flows near the town. A few wells have been dug in the district about Loomis. They are all shallow, ranging in depth from 20 to 30 feet. They do not reach bed rock, but lie wholly in the mantle rock or soil.

PACIFIC COUNTY.

General statement.—Pacific County lies at the southwest corner of the State. The ocean border of the county is exceedingly irregular, due in part to a submergence of the coast and in part to the building out from the headlands of long sand spits. The surface rises gradually from tide water to the summit of the Coast Range, where a maximum height of 3,000 feet above the sea is attained. Much of the coast is low, and alluvial valleys extend for some distance up the streams. The annual rainfall is very heavy, varying from 65 inches at the mouth of the Columbia to 85 inches and over along the northern border. In this county the change in amount of precipitation is in a north-south rather than an east-west direction as is commonly the case. As elsewhere the large rainfall produces many streams and an extraordinary forest growth. The larger trees are closely surrounded by a very dense growth of minor forms, so that the forest as a whole is almost impenetrable.

With few exceptions all the rocks of the county are shales, sandstones, and conglomerates of middle Tertiary age. All of these disintegrate readily when exposed to the atmosphere, so that there is a heavy mantle of incoherent porous material many feet in depth. Within this soil there is generally an abundance of water, so that shallow wells and springs form the main sources of domestic supply.

Municipal systems.—Springs afford the water supply for Ilwaco, but they are not very satisfactory and in the near future some other source must be sought. The present supply is not of the best quality and will soon be inadequate. Contamination is due chiefly to decaying vegetable matter. A gravity system of waterworks is used. Ilwaco is situated on a plain which rises but little above high tide. Wells are not used at all, because the water within them is unfit for drinking purposes.

The supply of water for Southbend is obtained from springs. In this way water of excellent quality is had, free from contamination, and in quantity believed to be sufficient for all future needs. The water is carried from the springs and distributed about the town by a gravity system. Very few wells are used about Southbend, and in none of them is the water satisfactory. The wells vary in depth from 10 to 60 feet.

PIERCE COUNTY.

General statement.—Pierce County extends from the summit of the Cascades on the east to Puget Sound on the west, and from King and Kitsap counties on the north to Lewis and Thurston counties on the south. In the vicinity of the sound the surface is that of a plain with a general height of 300 to 400 feet above sea level. Eastward the plain gives way to hills, which in turn soon merge into the high mountains forming the eastern third of the county. Mount Rainier lies in Pierce County, and immediately about it and to the northeast high peaks and deep valleys are very conspicuous.

The lowest annual rainfall is in the neighborhood of Tacoma, where it averages 45 inches. It increases eastward and in the mountains is about 60 inches. Upon the sides of Mount Rainier and the neighboring high mountains the precipitation is principally in the form of snow, and large snow fields and glaciers are found. By the precipitous descent of many of the large streams waterfalls of much economic importance have been produced. Some of the waterfalls are now being utilized for power purposes. The heavy rainfall of the mountains insures an ample supply of the purest water for the cities about the sound or upon the plains.

In the region about Burnett, Wilkeson, Carbonado, and Fairfax the outcropping rocks are chiefly clastic sediments of Eocene age. They are coal bearing, and at the places above mentioned coal mines are now in operation. The extent of the sedimentary series is unknown, since eastward it passes under the lavas of Mount Rainier and westward it disappears beneath the heavy mantle of glacial sediments which covers the western third of the county. The glacial deposits for the most part are made up of coarse gravels and sands, into which the water sinks after each rainfall, so that the drainage is chiefly underground. In the western part of the county there are but few streams save those which have their origin in the hills and mountains. Ordinarily a large quantity of good water is obtained in wells having a depth of 40 to 50 feet. Springs are very abundant and it is from this source that the principal towns of the county derive their water supplies. The springs are commonly found at the bases of the hills, and from them the water usually issues in the form of streams. Not only are the springs numerous, but the quantity of water that flows from some of them is phenomenal.

Municipal systems.—A well situated on an island in White River, near the town, supplies Buckley with water. From this source, by pumping, a very large supply may be obtained, ample for present and future needs. The water is of good quality, there being no known sources of contamination. In the region about Buckley the wells vary in depth from 30 to 40 feet, the water-bearing materials being beds of sand and gravel. The latter are overlain by glacial till or hardpan, so that the wells suffer no contamination from the surface.

The water for Carbonado is obtained from springs located in some gravel beds overlying the coal-bearing rocks. The supply is sufficient for the present and doubtless will be enough for all future needs. A gravity system of waterworks is in use. The water is used for boilers as well as for domestic purposes. There are no wells in Carbonado.

Springs furnish a supply of water for Orting. The water is not contaminated and is very satisfactory. The supply is ample for all the demands made upon it. Other springs near by may be utilized if necessary. A gravity system of waterworks is used. In the region about Orting are a few wells, their depths varying from 14 to 18 feet. The wells are wholly in glacial materials, not reaching the bed rock in any case. The water in the wells is excellent and abundant, usually rising to the surface in the winter months.

The water used in Puyallup comes from Maplewood Springs.

These springs lie within the city limits and have a flow of 20,000,000 gallons daily. The water is of good quality. It is distributed through the town by a gravity system. Puyallup is located on the flood plain of Puyallup River near where it enters the sea. The wells that have been dug in the alluvium of the valley do not yield good water and hence are rarely or never used.

The water system in South Tacoma is owned by Calvin Phillips & Co., who obtain a daily supply of 150,000 gallons from wells. The water is free from any contamination and is quite satisfactory. The usual depth of wells about South Tacoma is 40 to 50 feet. The wells penetrate beds of gravel and sand and in no instance reach bed rock.

For Sumner the water is obtained from a spring located on a hillside 1 mile east of the town. The spring is sufficiently above the level of the town to give a good head to the water, so that it may be distributed by gravity. The supply is ample for present needs, and there are other good springs near by which may be utilized in the future should the needs of the town so demand. No wells are used in the valley about Sumner, all of the water for domestic purposes being piped from the springs on the hillsides which border the valley.

The city of Tacoma obtains its water supply from Clover Creek and some springs. From the former the major portion of the water used in the city is obtained, but the spring water is more satisfactory. The quantity obtained is hardly sufficient for the needs of the city and, as additional sources of supply, three deep wells are being drilled. From the creek and springs water is pumped into reservoirs, from which it is distributed by gravity throughout the city. Tacoma is located upon a plain composed of glacial sediments, till, clay, sand, and gravel, which yield an abundant supply of good water. The depth of the wells varies from 30 to 100 feet. In general the water-bearing strata are overlain by clay or till, so that surface contamination is reduced to a minimum.

A sanitary analysis of water from Clover Creek and springs, made February 23, 1901, by Prof. H. G. Byers, of the University of Washington, resulted as follows:

Analysis of water from Clover Creek and springs.

[Parts per million.]

Total solids	47.20
Nonvolatile solids	25.20
Volatile solids	22.00
Oxygen consumed	6.34
Chlorine	4.40
Nitrogen as free ammonia	.035
Nitrogen as albuminoid ammonia	.080
Nitrogen as nitrites	None.
Nitrogen as nitrates	None.

Springs.—Near the town of Carbonado, in sec. 4, T. 18 N., R. 6 E., the water issues as a stream from some gravel beds which overlie the coal measures at this place. The spring yields sufficient water to supply the town of Carbonado and the boilers of the Carbon Hill Coal Company.

The Orting Light and Water Company own three springs in sec. 29, T. 19 N., R. 5 E. These springs are small, but afford enough water to supply the town of Orting. They are located upon a hillside, where the water issues as small streams from beds of sand and gravel. The water carries a little sand and is somewhat muddy after hard rains. The flow is said to be a little stronger in summer than in winter.

Maplewood Springs are located near Puyallup, in sec. 32,T. 20 N., R. 4 E. The water issues in streams from beds of gravel at the base of a bluff. The flow is estimated at 20,000,000 gallons per day. The town of Puyallup and a portion of Tacoma are supplied with water from this spring. The spring is owned by the city of Tacoma.

SAN JUAN COUNTY.

General statement.—San Juan County comprises a group of islands lying between Whatcom and Skagit counties in Washington and the island of Vancouver. These islands have rocky, irregular, deeply indented shores and represent the tops of submerged mountains. The surface of some of the islands is that of a plain, but in most cases there are high hills or semimountains. The principal hills are on Orcas Island, the highest point, Mount Constitution, rising 2,200 feet above the sea.

Since the San Juan Islands lie to the leeward of the mountains of Vancouver Island, they have a rainfall that is less than the average of western Washington. The yearly rainfall is between 30 and 35 inches. This is enough to support but a moderate forest growth, so that the trees are not so large as in some parts of the State and there is but a small amount of undergrowth. The rainfall is ample for agricultural purposes and excellent crops are raised.

The rocks of the northernmost islands of the group are of upper Cretaceous age and are a part of the coal-bearing series of the islands of British Columbia. South of the sedimentary rocks just mentioned, and forming the major portion of the islands, are metamorphic and igneous rocks of undetermined age. All of the islands have been glaciated, and oftentimes the rocks are deeply furrowed. The glaciers laid bare the rocks in some instances, and over much of the surface but a thin soil was left. The area of tillable land is thereby largely reduced and limited to the lower valleys. On a few of the islands the water supply is scant and the problem of securing water for domestic purposes is a difficult one. Only a meager supply of surface water is obtained because of the scant rainfall. The slight depth of soil makes it necessary to dig the wells in bed rock in most places. In some instances, however, as about Friday Harbor, the soil is of sufficient depth to yield a water supply by means of shallow wells.

Municipal systems.—The water supply for Friday Harbor comes altogether from wells. These yield water of good quality, which thus far has been quite satisfactory. The wells are all shallow, not often reaching a depth exceeding 18 feet. The water is obtained from beds of gravel. These are overlain by clay, thus preventing surface drainage from entering the wells. A good water supply for the town of Friday Harbor can be had in Sportsmans Lake, which is 3½ miles away and lies at an elevation of about 75 feet above the town. The lake covers 90 acres and is fed by springs.

SKAGIT COUNTY.

General statement.—Skagit County is in the northwestern part of the State and lies between Whatcom County on the north and Snohomish County on the south. It extends from Puget Sound on the west to the summit of the Cascades on the east. The coast is very irregular. The topography of the western part of the county is that of a plain lying but little above the sea. The eastern half is very rough and broken and embraces some of the most rugged portions of the Cascades. A prominent feature of the surface is the great valley of Skagit River, which has an east-west course through the county and upon the broad delta of which the principal towns are located. Dikes have been built along the coast and the lower reaches of the river to keep the alluvial plain from being overflowed. The tide runs up Skagit River for about 20 miles.

The yearly rainfall varies from 30 inches along the coast to an average of 50 inches in the mountains. Practically all of the region was once forest covered, and the cedars of the Skagit Valley are among the largest and best to be found in the State. The timber of the broad alluvial plain along the lower course of the river has been largely removed and excellent farms have taken its place. The most valuable farm land in the State is found here, the amount of rainfall and the excellent quality of the soil being conducive to very high agricultural returns.

In the region south of Hamilton and immediately about Cokedale are outcropping Tertiary sandstones and shales which are coal bearing and in which coal mines have been opened. The extent of these sedimentary areas is unknown, since they are largely concealed by the alluvial deposits of the river, glacial sediments, etc. East of

Hamilton is a north-south belt of slates and schists containing small bodies of iron ore. Among the islands at the western end of the county are frequent outcrops of slates, schists, and other metamorphic rocks. Along the borders of the valley of the lower Skagit are thick deposits of glacial sediments, from which water is often obtained by means of wells and springs. The towns located in the valley of the Skagit may secure supplies of water either from the springs on the adjacent hillsides or from shallow wells that have been sunk into the sands and gravels of the river plain.

Municipal systems.—The town of Anacortes obtains its water from Lake Heart, which is fed by springs. The lake is about 250 feet above the town, so a gravity system of waterworks is used. Lake Heart, although now supplying enough water for the use of the town, will in time become inadequate. Other desirable sources of supply may easily be found in Cranberry and Whistler lakes, which lie near the town. The water now used is of good quality and is quite satisfactory. Some of the wells of the region are shallow, but the best water is obtained at a depth of about 80 feet. Not even the deepest wells enter bed rock, the materials passed through being clay above, with beds of gravel below.

Hamilton secures its water supply exclusively from wells. These are shallow, since the town is located on the flood plain of Skagit River. The wells range in depth from 10 to 25 feet. The height of water in the wells depends upon the stage of water in the river. The water in the wells all comes from the river by seeping through the coarser materials of the flood plain. In each well a lateral movement of the water in the same direction as the flow of the river may be readily seen.

The water that is used at Laconner is brought from a spring by a gravity system. The water is of good quality, and is ample in amount for present demands, but may need to be supplemented in the future.

Water for the use of the town of Mount Vernon is obtained from a large spring. From the spring water is pumped into a reservoir located on a hill above the town and is then distributed by gravity. The water is very pure, there being no sources of contamination, and it is sufficient in amount for present and future needs. The wells of the region range in depth from 10 to 14 feet. They do not enter bed rock, but are altogether in the alluvium of the valley. In some instances the well water is not of good quality.

SKAMANIA COUNTY.

General statement.—Skamania County lies on the southern border of the State, south of Lewis County, between Yakima and Klickitat counties on the east and Cowlitz and Clarke counties on the west. The proportion of low plain to high mountain is less than in any other county in the State. With the exception of a very narrow plain along Columbia River the entire county consists of rugged mountains which have a general height of about 5,000 feet above sea level. From east to west the county covers very nearly the entire width of the higher Cascades in this part of the State. The highest point is Mount St. Helens, with an elevation of about 10,000 feet, standing near the northern border line. St. Helens is a volcano that is said to have shown slight signs of activity since white settlers first came to Washington. It has suffered but little erosion and is symmetrical in outline.

The rainfall ranges from 60 inches or a little more in the northwestern part to 40 inches on the southeastern border. The elevation is such that the rainfall is heavy. It should be noted, however, that not all of the precipitation is in the form of rain, but that some of it, especially in the northwestern part of the county, is in the form of snow. With the exception of a few mountain peaks the surface is entirely forested, and over one-half of the county is within the limits of the Mount Rainier Forest Reserve.

Little is known of the geology of the county. Nothing but basalt, presumably belonging to the Columbia River lava, appears along Columbia River. About 15 miles north of the river, northeast of Skye, outcrops of granite occur. These outcrops are believed to be at the southern end of a belt of granite which runs northward through the county, passing between Mount St. Helens on the west and Mount Adams on the east. The warm springs which occur at Cascades seem to indicate that there are igneous rocks at moderate depths in that vicinity which are not yet entirely cooled. Very little information is at hand regarding the details of the water resources of the county, since it is very sparsely peopled. The only settlements are located in the immediate vicinity of Columbia River.

Springs.—Near Cascades post-office, on Columbia River, in sec. 16, T. 2 N., R. 7 E., is a mineral spring owned by Thomas Moffett. The water seeps out at the base of a hill, and flows 25,000 gallons daily, with no variation from season to season. The water has a temperature of 96° F. Gas is constantly escaping and the water is known to carry iron and sulphur. At the spring a bath house and a hotel of 25 rooms were erected some years ago. Plans have been drawn for a new hotel of 100 rooms, new bath houses, and a swimming tank 60 feet long, 20 feet wide, and 7 feet deep. The water is of medicinal value, being especially healthful in diseases of the stomach and kidneys. The water is bottled and placed on the market, $1,200 worth having been sold in 1902.

SNOHOMISH COUNTY.

General statement.—Snohomish County is located in the northwestern part of the State, between Skagit County on the north and King County on the south, and extends from the summit of the Cascades to the shores of Puget Sound. The surface of the western third of the county is that of a low plain either level or covered with low hills. The eastern two-thirds has a mountainous topography, varying from the low foothills on the west to the lofty snow- and ice-covered peaks on the main divide. The mountains have been trenched by Skykomish River and the North and South forks of the Stilaguamish, all of which flow in deep valleys. These rivers have in general a westerly course, and the watersheds are separated by bold spurs which extend outward from the main mountain mass.

There is a considerable difference between the rainfall of the lowlands along the coast and that in the high mountains. Along the western border of the county the annual rainfall averages 35 inches; at the foothills of the mountains it is 50 inches; while within the mountains, and especially toward the eastern summit, it reaches 60 inches and over. In the vicinity of Monte Cristo, about Glacier Peak, and elsewhere in the high mountains the snowfall is very heavy and great fields of snow and many glaciers are the result. With the exceptions of the high mountains that are covered with snow or ice, or are barren of soil, almost all parts of the county are heavily forested. The best timber is found on the plains and the low hills in the western part of the county and in the larger valleys of the mountains. The northeastern part, embracing over a third of the county, is included in the Washington Forest Reserve.

In the western end of the county the bed rock appears at very few places because of the great thickness of the glacial sediments. There are a few outcrops of Tertiary sandstones and shales, which are not coal bearing, as far as observed. The mountainous portion is composed of a great complex of metamorphic rocks with many varieties of extrusive and intrusive igneous rocks. The water supply of the county is obtained in part from the mountain streams and in part from the glacial deposits, in the latter case either from springs or by means of wells. The several sources afford a very satisfactory supply, and there is no part of the county that is not abundantly provided with water of the finest quality.

Municipal systems.—The town of Arlington secures water from springs, wells, and Stilaguamish River. Both springs and wells are very satisfactory, a large supply of excellent water being thus obtained. The wells vary in depth from 20 to 30 feet. They do not enter the rock, but have been dug wholly in clay, sand, and gravel.

Edmunds secures its town supply of water almost wholly from springs, only a few wells being in use. The springs yield a supply that is satisfactory in both quality and quantity. A gravity system of waterworks is used.

Everett obtains a supply of water from 2 creeks, one flowing within a mile and the other within 2½ miles of the city. From these streams the water is conveyed through pipes of 22 and 8 inches in diameter to a reservoir which has the capacity of 1,200,000 gallons. From the reservoir the water is distributed by a gravity system throughout the city. The water is free from contamination and highly satisfactory in every way. The wells in the region about Everett vary in depth from 15 to 115 feet, water being usually found at about 100 feet. The materials penetrated are surface soil, glacial till or hardpan, and finally sand or gravel, which yield the water. Bed rock is not reached even in the deepest wells. A large supply of good water may be obtained from the wells, which is ample in quantity for domestic demands. The following sanitary analysis of the city water of Everett was made by Prof. H. G. Byers, of the University of Washington, on January 10, 1901:

Analysis of city water of Everett.

[Parts per million.]

Total solids	300.80
Nonvolatile solids	252.80
Volatile solids	48.00
Oxygen consumed	7.27
Chlorine	4.80
Nitrogen as free ammonia	0.020
Nitrogen as albuminoid ammonia	0.050
Nitrogen as nitrites	None.
Nitrogen as nitrates	None.

In Marysville the water supply comes exclusively from wells. The wells are all shallow, since the town is located on the flood plain of Snohomish River. The water is soft, of good quality, and satisfactory for the present, at least. It is planned to use at some future time the water of Lake Stephens, which is located conveniently near.

The water supply for Monroe is obtained from two small creeks. In this way very pure water is had, and in quantity sufficient for present and future needs. A gravity system of waterworks is in operation. The wells are from 18 to 50 feet in depth. None of them enter rock, all being wholly within the alluvial materials of the river valley. An analysis of water from the Monroe supply was made by G. L. Tanzer, of Seattle, on August 3, 1903. He found that there was 0.049 grain of solid matter in 1 liter (33.81 fluid ounces) of water. A qualitative analysis of the solid matter showed it to contain magnesium and sodium chlorides, with a trace of calcium carbonate. No ammonia, nitrogeneous matter, iron, or silicates were found.

Monte Cristo obtains a water supply from a mountain stream, using a gravity system. The water comes directly from the snow fields near by and is very cold and pure. The quantity is greater in autumn and spring than in other seasons, but probably will always be equal to every demand. Besides its uses as a domestic and boiler supply it is also used in an ore concentrator.

The water supply of Silverton comes from mountain streams which head in the fields of snow and ice near the town. The water is therefore of exceptional purity and may be had in quantity sufficient for all possible needs. It is used as a domestic supply, for water power, and in concentrating ore.

Snohomish secures its supply from Pilchuck River, a stream heading to the east in the Cascade Mountains. The water is pumped into a reservoir having a capacity of 500,000 gallons and is then distributed by gravity. There are no sources of contamination and the water is of good quality. The quantity is sufficient for all future needs. The wells about Snohomish range in depth from 15 to 55 feet. In digging the wells glacial till or hardpan is first passed through, and the water is obtained from the beds of gravel that lie below. The following sanitary analysis of water from the city supply was made by Prof. H. G. Byers, of the University of Washington:

Analysis of city water from Snohomish.

[Parts per million.]

Total solids	41.50
Nonvolatile solids	23.22
Volatile solids	18.28
Oxygen consumed	3.75
Chlorine	4.00
Nitrogen as free ammonia	.010
Nitrogen as albuminoid ammonia	.093
Nitrogen as nitrites	None.
Nitrogen as nitrates	.400

SPOKANE COUNTY.

General statement.—Spokane County lies in the extreme eastern part of the State, with Stevens County on the north, Lincoln County on the west, and Whitman County on the south. In the main the surface is that of a plateau, with an average height of about 2,000 feet above the sea. The only exceptions to the plateau aspect to be noted are the mountains in the northeast corner, of which Mount Carlton is the highest, and the high hills or low mountains in the southeastern part along the Idaho boundary. The principal stream, Spokane River, flows in a broad, shallow valley from the eastern border of the county to the city of Spokane; at this point it enters a canyon, of very moderate depth at first, but gradually deepening as the river flows northwestward to join the Columbia.

The average rainfall is about 20 inches per year. The precipitation on the western border is somewhat less than this, while on the eastern side it is a little more. The result is that in a general way the eastern half of the county is forested, while the western half is a prairie. The grassy plains have been largely replaced by wheat fields, since the rainfall is always ample to secure a crop of this cereal. The forest growth is rather sparse, the trees are of only moderate size, and there is little undergrowth.

Spokane County lies partly within the Columbia River lava field, the bed rock of the southwestern half being basalt. As this is the border line of the lava field the basalt is comparatively thin and the underlying rocks occasionally appear through it. The northwestern part of the county is chiefly a granite region, with occasional areas of gneiss and schist. Among these rocks basalt often appears in the form of narrow tongues which have extended outward from the main mass of lava. The valley of Spokane River in Glacial time was almost entirely filled by a gravel train, only a minor portion of which has been removed. At Spokane Falls is a jutting ledge of basalt, and the river drops 130 feet. Within the gravels and sands of the river valleys good water is obtained by means of deep wells. Upon the lava plateau domestic supplies of water are secured from wells ranging from 30 to 135 feet in depth. Some of the basalt is porous, and where such rock outcrops along the bases of hills springs are often found.

Municipal systems.—Cheney obtains a water supply from a lake and from wells. The lake supply is the more commonly used, but water from the wells is more satisfactory. An ample amount is secured for the present and doubtless for all future needs. A direct pressure system of waterworks is in use. The wells vary from 30 to 50 feet in depth, water being most commonly found at 40 feet. They all enter basalt after passing through a layer of clay at the surface. Very good water is secured. The water level scarcely varies from season to season, and is not affected by pumping.

The town of Medical Lake secures water from Clear Lake, located 3¼ miles to the south. The water is hard, but quite satisfactory otherwise. A supply sufficient for all possible demands may be obtained. In the wells about Medical Lake water is usually found at a depth of 15 feet; but the range of depth of the wells is from 10 to 40 feet. The wells are all in basalt, the porous or scoriaceous layers of the rock being water bearing.

An analysis of the water of Medical Lake, made by G. A Mariner, of Chicago, is as follows:

Analysis of water of Medical Lake.

[Parts per thousand.]

Silica	0.1825
Alumina and iron oxide	.0120
Calcium carbonate	.0031
Magnesium carbonate	.0040
Sodium chloride	.2869
Potassium chloride	.1616
Sodium carbonate	.1089
Potassium carbonate	Trace.
Lithium carbonate	Trace.
Borax	Trace.

Hillyard obtains a supply of water from deep wells. These are commonly from 190 to 200 feet in depth and are wholly in gravel. The water is soft and of the best quality. The supply at present is sufficient for all needs, but it is doubtful if it will be ample for the future.

Latah uses wells exclusively as a source of water supply. Later on water may be taken from a large spring above the town. The wells are shallow, as a rule, varying in depth from 25 to 40 feet. They enter rock, and a layer of clay at the surface tends to prevent contamination from above. The water level varies but little throughout the year. One well sunk to a depth of 135 feet flows constantly.

The city of Spokane obtains its supply of water from Spokane River. The pumping plant is on the river bank about 5 miles above the city. A direct pressure system of waterworks is used. There are no sources of contamination and the water is of a high degree of purity, as well as ample in quantity for all probable future needs.

The following sanitary analysis of city water from Spokane was made on April 23, 1901, by Prof. H. G. Byers, of the University of Washington:

Sanitary analysis of city water from Spokane.

[Parts per million.]

Total solids	50.24
Nonvolatile solids	34.43
Volatile solids	15.81
Oxygen consumed	2.13
Chlorine	1.50
Nitrogen as free ammonia	.004
Nitrogen as albuminoid ammonia	.0363
Nitrogen as nitrites	None.
Nitrogen as nitrates	.018

Deep wells.—The Hillyard Town Site Company has a well which is used to supply the town of Hillyard with water. It has a diameter of

44 inches and a depth of 200 feet. It was dug in 1900 at a cost of $500. The amount of water obtained is about 50,000 gallons per day. The water level in the well rises and falls with the water level of Spokane River, which flows not far away.

Springs.—William Forthman owns a spring near Latah, in sec. 26, T. 21 N., R. 45 E. The water issues as a small stream at the foot of a hill. The spring has a minimum flow of 720 gallons per day and is much stronger in the springtime. The water is soft, clear, and of excellent quality. It is used for general farm purposes. In the vicinity of Latah are a number of large springs.

STEVENS COUNTY.

General statement.—Stevens County lies in the northeast corner of the State, bordering on Idaho and British Columbia. The surface is characterized by three conspicuous mountain ridges and three north-south valleys. The ridges lie between Columbia and Colville rivers, between Colville and Pend Oreille rivers, and east of the latter stream along the county boundary. Of the three ridges the first one mentioned is the lowest, with an average height of about 4,500 feet. The second and third ridges have a maximum elevation of about 7,000 feet. Columbia River flows in a deep valley that is usually bordered by glacial terraces. The valley of Colville River is wide and the stream has an extensive flood plain, which overflows at certain seasons of the year. For the first 50 miles of its course within the county Pend Oreille River flows very slowly, in a broad valley that is bordered with much agricultural land; farther down the stream crosses a belt of harder rocks, in which it flows in a long, tortuous canyon.

The rainfall averages about 20 inches per year. This is sufficient to permit of agriculture without irrigation. Practically the entire county was once forested, although the region seems to be near the border land of forest and prairie. The trees do not grow very near together and the undergrowth is very scant. As a rule the grasses grow everywhere among the trees. The forest is being removed at a rapid rate, the demands of the lumbermen on one hand and of the farmers on the other tending toward the deforesting of the county in a comparatively short time.

Stevens County is largely a region of crystalline rocks. The north-south ridges between the principal streams are composed chiefly of granite. Flanking the granites and within the valleys are large areas of marbles, quartzites, slates, and other metamorphic rocks. The marbles occur very generally throughout the county and are of economic importance both as an ornamental stone and for the manufacture of quicklime. At several places are outcrops of coal-bearing sandstones and shales, which represent remnants of lacustrine sediments of

Tertiary time. The basalt of the Columbia River lava extends a little way into the county along the southern boundary. The towns depend for the most part upon streams for their water supplies. The water in virtually every stream is free from contamination and is of excellent quality. In general, the soil is of sufficient thickness to contain enough water for the domestic supplies needed in the smaller towns and through the country. The wells for the most part are shallow and do not often exceed 40 or 50 feet in depth.

Municipal systems.—Bossburg secures water from Columbia River, beside which the town is situated. The water is pumped into a reservoir, from which it is distributed about the town by gravity. The supply is satisfactory in every way. There are no wells about Bossburg, but there are some springs which are utilized.

Colville depends mainly upon springs, but in part upon two streams, for its water supply. The water from all of these is of fine quality, there being no sources of contamination. A gravity system of waterworks has been installed. The wells about Colville range in depth from 10 to 30 feet, the usual depth being 20 feet. The water comes from beds of sand, which are overlain by clay.

Water for Marcus is taken from Columbia River. The water is satisfactory from all standpoints. The wells vary from 18 to 60 feet in depth. Beds of clay are first penetrated, then sand, and finally gravel.

Northport obtains its water supply from Deep Creek, a small stream emptying into Columbia River. There are no sources of contamination, and the water is satisfactory, although very hard. A large amount may be secured, sufficient for all future needs. The water is first pumped into tanks which stand upon a hill above the town and is then distributed by gravity. Besides its domestic use it is also used as a boiler supply by the Northport Smelting and Refining Company.

The water for Springdale is taken from a mountain stream. The spring flows for some distance over limestone, hence the water contains some lime. The supply is believed to be sufficient for all future needs. A gravity system of waterworks is in use. The wells about Springdale range from 30 to 100 feet in depth, water being commonly found at depths of 40 to 50 feet. The more shallow wells are wholly in the soil or mantle rock, but the deeper wells all enter bed rock.

Deep wells.—In sec. 9, T. 35 N., R. 39 E., near Colville, the Pacific States Oil Company drilled a well in 1901 when prospecting for oil. The total depth reached was about 700 feet. At the top the well has a diameter of 10 inches, at the bottom 6 inches. A water-bearing stratum was reached at 400 feet, and water now flows from the well mouth at the rate of 3 or 4 gallons per minute. The cost of the well was $3,000. In drilling the well, beds of limestone, sandstone, limestone, shale, and sandstone were passed through in succession.

THURSTON COUNTY.

General statement.—Thurston County is located in the southwestern portion of the State, at the head of Puget Sound, with Chehalis County lying between it and the Pacific Ocean. The county lies entirely within the basin of Puget Sound and the surface is essentially that of a low plain. For the most part the plain is quite level, with here and there occasional low hills. In the western part of the county the Black Hills rise 300 or 400 feet above the general level. In the southeastern part of the county there are a few low hills which mark the extreme outliers of the Cascades. The Puget Sound shore is very irregular, abounding in indentations and bordered by numerous islands.

In the central part of the county the annual rainfall averages 50 inches. In the eastern and western parts it is 60 inches or a little more. The precipitation is practically altogether in the form of rain, since falls of snow occur very rarely.

The bed rock is not often exposed in Thurston County. In the neighborhood of Tenino and Bucoda there are occasional outcrops of sandstone, which are of economic importance, as they afford a good grade of building stone, and also contain coal, which has been mined to some extent. In the northwestern part of the county, at Gate, there are several outcrops of basalt, but how far north, within the Black Hills, this rock extends is not known. Glacial sediments abound over nearly the entire county. These sediments are usually coarse gravels which represent outwash plains. Oftentimes the gravel plains are soil covered to such a slight degree that they are almost barren. Upon the plains the forest growth when present is very sparse and prairie conditions often prevail. The rainwater sinks away quickly into the gravels and the drainage is largely underground. The streams are few, only the larger ones flowing persistently throughout the year. Occasionally a good soil covers the gravel plains and good farming land is found. The hills noted above are heavily forested, and from them several streams flow out upon the plains. An ample supply of water is easily obtained throughout the county. Within the region of the gravel plains water is often obtained from springs and may always be had by means of wells, which rarely exceed 50 feet in depth. From the beds of sand and gravel in the vicinity of Olympia excellent water has been obtained from wells that vary from 125 to 175 feet in depth, the water sometimes outflowing at the surface.

Municipal systems.—The water supply for Olympia is obtained from springs. The water is pumped into a reservoir, from which it is distributed by a gravity system. At the present time about 3,000,000 gallons per day are obtained. This will doubtless prove sufficient for all future needs.

The Tenino water supply comes entirely from wells, which have an average depth of about 35 feet and are wholly in sand and gravel. The supply of water, while ample for present needs, will doubtless have to be superseded by a larger supply in the future.

Deep wells.—On the capitol grounds in Olympia some wells have recently been drilled in order to secure a water supply for the capitol building. No rock was penetrated in drilling the wells, the water-bearing material being sand. Two of these wells have depths of 152 feet each, and the third has a depth of 138 feet. Each well has a diameter of 2 inches. They are all flowing wells, the water rising about 2 feet above the ground. From the deeper wells flows of 6 and 4 gallons per minute are obtained, while from the third well a flow of 2 gallons per minute is had. The wells are located about one-fourth mile from the shore of Puget Sound and their mouths are 25 or 30 feet above mean tide. The rate of flow diminishes at low tide and increases at high tide. The wells have been cased throughout with 2-inch casing. The cost of drilling the wells was $1 per foot.

WALLAWALLA COUNTY.

General statement.—Wallawalla County is located in the southeastern part of the State, along the Oregon boundary, and east of Columbia and Spokane rivers. The region along Columbia River is very low, being but 300 or 400 feet above the sea. From this low plain there is a gradual ascent eastward in the direction of the Blue Mountains. The eastern part of the county is a region of high, rolling hills, with deep ravines or valleys. The hills in outline show the influence of the wind, and many of them are essentially of eolian origin. The prevailing winds are from the southwest, and hence the hills have their more moderate slopes upon their southwestern sides, while their steeper slopes are to the northeast.

The rainfall shows a very close relationship to elevation. In the lowest part, along Columbia River, the annual rainfall amounts to 10 inches or a little less. In a north-south belt through the center of the county it is 15 inches, and in the eastern part it reaches 20 or 25 inches. This is sufficient to afford a tree growth which, though sparse at first, becomes of considerable importance when the summit of the Blue Mountains is reached. Through the central part of the county trees do not grow naturally, and prairie conditions prevail. At the western end of the county, where the rainfall is least, grasses give way to sagebrush. In this part of the county irrigation is necessary in order that agriculture may be carried on successfully. The rolling prairies of the major portion of the county are famous wheat producers, and in the neighborhood of Walla Walla very fine fruit is raised.

In the northwestern part of the county the rocks are in the main sandstones and shales, which were deposited in a lake in middle Tertiary time. Along the Snake and the Columbia these rocks are largely covered by alluvial deposits. In the remaining part of the county the bed rock, as far as known, is altogether basalt. Usually the rock is deeply buried by the heavy mantle of soil, and outcrops but rarely. Springs often occur along the bases of the hillsides, wherever porous basalt appears at the surface. The wells are usually shallow and dug entirely within the soil. The deep well which has recently been drilled near Walla Walla is of great importance, since it has established the fact that an artesian basin exists here, and that flowing water may be secured at depths of from 500 to 600 feet.

Municipal systems.—The water supply of Walla Walla is secured chiefly from springs, but in part from infiltration ditches. The amount of water is barely sufficient in the dry season, and a larger supply is now being developed at a point about 3 miles above the city.

A sanitary analyses of the Walla Walla city water, made on April 12, 1901, by Prof. H. G. Byers, of the University of Washington, resulted as follows:

Sanitary analysis of city water from Walla Walla.

[Parts per million.]

Total solids	81.67
Nonvolatile solids	62.86
Volatile solids	18.81
Oxygen consumed	2.89
Chlorine	1.50
Nitrogen as free amonia	.008
Nitrogen as albuminoid ammonia	.0267
Nitrogen as nitrites	None.
Nitrogen as nitrates	.452

Waitsburg obtains a water supply from springs in autumn, winter, and spring, and from a creek in summer. The springs afford excellent water, and it is planned to replace the creek water by water from deep wells. A gravity system of waterworks is in use. The wells about Waitsburg vary in depth, the shallow ones being wholly in soil and broken rock, while the deeper ones enter the bed rock. In wells of the first type water is usually found at 15 to 25 feet, while in the second instance the usual depth is 40 feet.

Deep wells.—On the farm of the Blalock Fruit Company, near Walla Walla, a well has recently been drilled (completed May 1, 1903). It has a diameter of 6 inches and a depth of 564 feet. The first rock encountered was basalt, at a depth of 540 feet. The well is a flowing one, the rate of flow being 130 gallons per minute. The temperature of the water at the well mouth is 67° F. The well has been cased to a depth of 540 feet. The water is used in irrigation. The cost of drilling the well was $1,800.

WHATCOM COUNTY.

General statement.—Whatcom County lies in the northwestern part of the State, adjoining British Columbia, and extends from the summit of the Cascades to the Strait of Georgia. Topographically the surface presents two distinct divisions, the plain of the western half and the high mountains of the eastern part. The average height of the plain is 200 or 300 feet above the sea. In the southeastern part of the county are a number of high hills, which give to the plain a broken character. The mountains begin somewhat abruptly, the transition from the plain to the real mountains being quickly made. The highest peak, Mount Baker, stands at the western front of the Cascades, and from this point to the divide on the east the whole area is very rugged. The high mountains have been deeply dissected, and this region is regarded as one of the most difficult to penetrate in the entire Cascades.

The maximum rainfall is 45 inches per year. This occurs in a north-south belt in the vicinity of Mount Baker and also in the northwest corner of the county. From Mount Baker eastward there is a gradual decrease in the rainfall, so that the amount is about 30 inches on the border of the county. Southwest of Mount Baker, also, the rainfall decreases to 35 inches in the vicinity of Bellingham Bay. Mount Baker and all of the highest mountains are covered with snow fields and glaciers. These serve as reservoirs and assure a constant flow to the streams throughout the year. The abundance of precipitation and the great elevations of the region give rise to waterfalls, which will be of great usefulness for power purposes. The falls of the Nooksack, with an effective head of water of 179 feet, are now being developed.

What is now the western part of the county was a large lake in Tertiary (probably Oligocene) time. The deposits made in this lake were mainly sandstones, with some conglomerate and a little shale. These rocks outcrop very commonly in the southeastern part of the county, but in the northwestern portion they are almost entirely covered with glacial sediments. The lacustrine sediments aggregate many thousands of feet in thickness, their extent in this direction being as yet unknown. They are coal bearing near the base. The principal mines for the mining of this coal are located at Blue Canyon, on the shore of Lake Whatcom. The mountainous part of the county is virtually unknown geologically, but the rocks are chiefly metamorphics and igneous intrusions, with great lava flows in the vicinity of Mount Baker.

Whatcom County is abundantly supplied with water. The mountain streams furnish a large amount of excellent water for the use of the towns upon the plains. There are also a number of glacial lakes, such as Whatcom, Padden, and Samish, which are natural reservoirs of good water. From the glacial sediments of the northwestern part of the county large quantities of water are obtained from springs or by means of wells. The glacial sediments are usually made up of alternating beds of till and water-bearing gravel and sand, and surface contamination is thereby eliminated.

Municipal systems.—The water supply for Blaine comes from springs. The water flows into a reservoir, from which it is distributed by gravity. The quality of water is very good, and the quantity sufficient for all future needs. The wells in use about Blaine are shallow, ordinarily not more than 14 feet in depth. Water is found in gravel, usually at a depth of 10 feet. The town supply is used in the boilers of sawmills, and in the salmon canneries, and for general domestic purposes.

Fairhaven obtains a water supply from Lake Padden, a glacial lake south of the city. A gravity system of waterworks is used. A large amount of water may be obtained from this lake, but if the supply should ever be insufficient water may also be taken from the South Fork of Nooksak River or from Lake Samish. The water from Lake Padden is very pure, as is shown by the following analysis, made by the Deakbof Drug and Chemical Company, of Chicago:

Analysis of water from Lake Padden.

[Grains per gallon.]

Silica	0.467
Calcium sulphate	.329
Magnesium carbonate	.129
Sodium and potassium sulphates	.606
Sodium and potassium chlorides	.401
Iron oxide	None.
Total solids	1.932

In Sumas wells are depended upon, primarily, as a source of water supply, although some small streams are used to a slight degree. Water obtained in this way is of good quality, although the quantity is hardly sufficient for present needs, and some other source must be provided in the future. It has been suggested that a deep well be bored as a future source of supply. Wells in and about the town of Sumas are driven wells, for the most part, and have a range in depth of 40 to 90 feet. Water is most commonly found between 40 and 60 feet. The glacial sediments about Sumas are thick, and the wells have been driven entirely in these. Beds of clay were usually encountered first, with beds of sand and gravel below, from which the water was obtained. In a few instances the water in the wells rises to the surface. The water level varies but very little from season to season.

The city of Whatcom obtains its water supply from Lake Whatcom. The lake is several square miles in area and is located in the hills southwest of the city. It lies at a sufficient height above the level of the town to give a good head to the water, so that a gravity system of waterworks may be used. The water is of excellent quality, the only sources of contamination being sawdust and other refuse from the sawmills on the shores of the lake. The catchment basin of the lake is of ample size and insures a large storage of water in the lake basin, so that the water supply will be sufficient for all the future needs of the city. The water is used for domestic purposes and in the many manufacturing plants which are located about Whatcom. The following sanitary analysis of water from Lake Whatcom was made March 16, 1901, by Prof. H. G. Byers, of the University of Washington:

Analysis of water of Lake Whatcom.

[Parts per million.]

Total solids	158.86
Nonvolatile soiids	116.52
Volatile solids	42.34
Oxygen consumed	2.03
Chlorine	3.80
Nitrogen as free ammonia	.004
Nitrogen as albuminoid ammonia	.033
Nitrogen as nitrites	None.
Nitrogen as nitrates	None.

WHITMAN COUNTY.

General statement.—Whitman County lies along the Idaho boundary, south of Spokane County and east of Adams County. The surface is in general that of a plateau, with an average height of about 2,000 feet above the sea. Rising above the plateau, especially along the eastern border of the county, are several high hills which represent the extreme outliers of the mountains of Idaho. Of such hills Steptoe Butte is a good example, rising about 700 feet above the plateau. The plateau is generally covered with low hills of a marked eolian type. From the profiles of these hills it is seen that the prevailing winds which fashioned them came from the southwest. Along the southern border of the county Snake River flows in a canyon which has a depth of from 2,000 to 3,000 feet below the level of the plateau. The principal tributaries of the Snake within the county likewise flow in canyons, and hence indicate that the dissection of the plateau is under way.

The average rainfall is about 20 inches. This decreases to 15 inches along the western border and increases to 25 inches in the higher portion along the eastern boundary. With the exception of a slight forest growth on the eastern margin and of a few trees which grow in the valleys along the streams, the entire county was once clothed with grasses. The rainfall is of sufficient amount to make the growth of wheat possible, so that wheat fields now cover almost every part of the plateau. Irrigation is employed only in the canyons of the larger streams, such as the Snake. Upon the terraces or benches that border the latter river large fruit ranches are found, the water for irrigation being supplied by the small tributary streams.

In the plateau above mentioned basalt forms the bed rock almost exclusively. The few buttes or hills along the eastern boundary, which project above the plateau, are composed of granites, gneisses, schists, quartzites, and similar rocks, which indicate the character of the floor upon which the basalt outflowed. Along the canyon of Snake River in two or three places granite appears, showing that the river in trenching the basalt is bringing to light the rocks beneath it. The walls of the canyon of Snake River show the basalt in a series of 8 or 10 practically horizontal flows. The plateau is covered with a deep soil and the underlying rock rarely appears. Because of its eolian nature the soil is of a very fine grain and has the property of retaining moisture to a very marked degree. Oftentimes wells dug only into the soil afford a good supply of water. The towns usually depend upon deeper wells drilled into the basalt for their water supplies. As a general thing these wells range in depth from 100 to 300 feet. In some instances, as at Pullman, water is obtained from beds of sand and gravel between the layers of basalt. In other cases very porous layers of basalt often afford a plentiful supply of water. In some cases flowing wells are secured, this being especially true when the wells are drilled in the bottoms of the canyons or in deep valleys. Springs are very common along the valley sides wherever porous basalt appears at the surface.

Municipal systems.—Colfax obtains its city supply from Palouse River. In this way very good water is obtained; but it is possible that in the future deep wells may be substituted as a source of supply. The water is pumped into a reservoir located on a hill above the city, from which it is distributed by gravity. The wells about Colfax range from 12 to 120 feet in depth. Water is usually found at a depth of about 40 feet. All the deeper wells enter the rock, which is basalt. No flowing wells have been found; in every instance the water must be pumped.

Oakesdale depends chiefly upon wells, although a few springs and cisterns are used. At some places the water is soft, but at other places it is hard. Generally speaking, there are no sources of contamination and the water is quite satisfactory. The wells on the hills about Oakesdale have been sunk to depths of from 45 to 60 feet in order to obtain water. On the plain at the foot of the hills they are shallow, ranging from 10 to 15 feet in depth. In the shallow wells a clay hardpan with sand and gravel below are the only materials penetrated, while all the deeper wells enter the basaltic rock. The supply of water in the wells is stationary, neither increasing nor decreasing as far as known.

Pullman obtains a water supply from artesian wells. The wells vary in depth from 100 to 130 feet, water being most commonly found at 100 feet. The wells are in basaltic rock, the water coming from beds of sand interstratified with the layers of basalt. About 150,000 gallons of water are obtained daily. The capacity of the wells, however, is such that this supply could be doubled if it were necessary. It is noted that the wells do not flow as strongly as they did when they were first drilled. A gravity system of waterworks is used, the water being first lifted by steam pumps from the wells to a reservoir. An analysis of the city water, made by Prof. Elton Fulmer, of the Washington Agricultural College and School of Science, shows the following composition:

Analysis of city water from Pullman.

[Grains per gallon.]

Silica (SiO_2)	3.49
Potash (K_2O)	.50
Soda (Na_2O)	1.75
Lime (CaO)	1.86
Magnesia (MgO)	1.31
Iron oxide (Fe_2O_3)	.06
Alumina (Al_2O_3)	.03
Sulphuric acid (SO_3)	.08
Carbonic acid (CO_2)	3.73
Chlorine	.15
Total solids	12.96

Tekoa depends entirely upon an artesian well for its water supply. From this well water of a good quality is obtained, there being no contamination as far as known. The supply is at present sufficient, but will not be large enough in the future. In the region about Tekoa water is most commonly found at a depth of about 100 feet, although some of the wells reach depths of 175 feet. All of the wells enter rock. In most instances the water rises to the surface, and in some cases reaches a height of 10 feet above the mouth of the well.

Uniontown obtains its water supply from a deep well. The water is soft and very satisfactory in every way, and the quantity is ample for present needs at least. The deepest wells about Uniontown have a depth of about 200 feet. These wells enter the rock and obtain water from beds of sand and gravel intercalated with basalt. There are some surface wells which do not enter the rock and which are from 7 to 10 feet in depth. In none of the wells does the water rise to the surface. The water level does not vary during the day or year and is not affected by pumping.

Deep wells.—About Palouse a number of wells have been drilled. In general they have a diameter of 6 inches and a depth of from 100 to 300 feet. The depth to the principal source of water is, on the average, 150 feet. The water is found in beds of sand which lie below a capping of basalt. From some of the wells the water flows, while in others the water level stands below the surface and pumping must be resorted to. The level does not vary during the day or year, the supply being constant from season to season. The water as a rule is hard, generally containing magnesia and iron. The usual temperature of the water at the well mouth is 50° F. The wells are mostly owned by farmers, and the water is used for general farm supply. The average cost of a well is $300, while the pumping machinery costs from $100 to $200. As a rule the wells are only partially cased, the length of casing varying from 20 to 120 feet.

In and about the city of Pullman are a number of artesian wells, of which the two owned by the city and used as a source of municipal water supply may be taken as types. One of these wells was drilled in 1890 and the other in 1899. They are located near the bed of a stream which flows through the center of the city. The mouths of the wells are at an elevation of 2,341 feet above the sea. Each well has a depth of 110 feet, with a diameter of 6 inches. The wells flow and the water rises to a height of 19 feet above the surface. The temperature of the water at the well mouth is about 60° F. The supply of water has decreased since the wells were drilled. Both wells are cased throughout with 6-inch heavy wrought-iron pipe. The cost of each well was about $450, and the cost of the pumping machinery necessary to lift the water to the reservoir was about $3,000.

In Tekoa there is an artesian well that was drilled in 1892 to serve as a source of water supply for the town. The well was drilled on a stream bed. It has a depth of 176 feet and a diameter of 6 inches. Only one water-bearing bed was found, that at the bottom of the well. The water rises to a height of 8 feet above the surface, and has a temperature of 76° F. at the well mouth. The water level has shown no seasonal variation, and the supply has been constant. The cost of the well was $750, and the cost of the pumping machinery was $1,000. The casing has been placed in the well only from the surface to solid rock. The Oregon Railroad and Navigation Company owns a deep well at this place, from which is obtained a water supply for locomotives.

YAKIMA COUNTY.

General statement.—Yakima County is located in the south-central part of Washington, between Columbia River and the summit of the Cascade Mountains. The surface presents a great diversity topographically. Columbia and Yakima rivers are bordered by broad, low plains. Between these streams are a number of ridges or low mountains which rise a few hundred feet above the general level of the plain. Southwest and west of Yakima River the plain merges into an even-topped plateau, which in the course of 20 or 30 miles gives way to the foothills of the Cascades. The mountains are comparatively low, with a general height of 4,000 to 5,000 feet, except in the vicinity of Mount Adams, in the southwestern part of the county, where they are much higher, reaching a maximum of 12,400 feet.

As the county lies partly within the Cascade Mountains and partly within the Columbia Plains, it has geologic features common to both provinces. The formations of those portions of the Cascades within the county are scarcely known at all, but are believed to consist mainly of metamorphic and igneous rocks typical of the interior of the range. Immediately east of Cowlitz Pass are limited areas of Tertiary shales and sandstones which contain seams of coal. The coal is a semi-anthracite, or a true anthracite in some cases. Along the eastern flank of the mountains are occasional flows of andesite, most of which are of a very late date.

The eastern part of the county lies within the Columbia Plains, and here the rocks belong almost wholly to two divisions, viz, the Yakima basalt and the Ellensburg formation. The Yakima basalt, according to Smith, has a vertical thickness in the canyon of Yakima River of more than 2,500 feet, and represents ten or more separate flows. For the most part the basalt is compact and heavy, but occasionally it is cellular or scoriaceous. In color it is black, except on weathered surfaces, where it usually has become brown. In a few instances the so-called ash beds, consisting of fine and coarse tuffs, are found interbedded with the dense compact basalt. The latter has usually a prismatic or columnar structure, the result of the contraction or shrinkage of the lava in the process of cooling. The Ellensburg formation lies directly on the Yakima basalt, and includes shales, sandstones, and conglomerates that, in the main, were deposited immediately after the last flows of lava. In some places there was a final outflow of lava a little while after the beginning of the deposition of the clastic rocks. The sediments of the Ellensburg formation accumulated to a thickness of 1,500 feet or more, and on the evidence of fossil leaves are known to be of Miocene age. These rocks are but partially consolidated, and have suffered considerable erosion, with the result that they have been wholly or in large part removed from much of the area that they once covered. This formation is of special interest. It contains water, and within it the artesian wells of the county have been drilled.

The Yakima basalt and the Ellensburg formation have been folded into a series of arches and troughs, or anticlines and synclines, that have, in general, an east-west direction. The general structure of the region is well shown along the course of Yakima River, which has cut directly or obliquely across the ridges and alternating troughs. As a rule the arches or ridges are comparatively long and narrow, and rise from 800 to 1,500 feet above the intervening valleys. The arches are almost invariably capped by basalt, the rocks of the Ellensburg formation being limited to the valleys and the lower flanks of the ridges.

The rainfall of Yakima County shows as great a variation in amount as is to be found in any area of similar size within the State. In the eastern portion the annual rainfall averages 10 inches or a little less. From the vicinity of North Yakima westward it increases regularly toward the summit of the mountains. Upon the plateau it ranges from 15 to 25 inches. In the mountains it varies from 30 inches in the foothills to a maximum of 50 inches along the summit. The effect of the rainfall upon the vegetation is of interest. The western end of the county is so well forested that it is included within the Mount Rainier Forest Reserve. The plateaus and hills of the central and eastern parts are bare of trees, but are abundantly covered with grasses. Along the low plains of Yakima and Columbia rivers the grasses largely disappear and sagebrush takes their place as the principal vegetal covering. Except for the growing of wheat upon the plateaus, no attempt is made to carry on agriculture without recourse to irrigation. The water for irrigation is obtained chiefly from the streams, but to some extent from artesian wells. The streams coming from the mountains, where the rainfall is heavy, carry a large amount of water. Even without the use of impounding reservoirs, enough water may be had to irrigate a large part of the plains. In the vicinity of North Yakima a number of deep wells have been drilled, which furnish sufficient water to irrigate large tracts of land. The character and extent of this artesian basin have been set forth in Water-Supply and Irrigation Paper of the United States Geological Survey, No. 55. The towns, as a rule, depend upon streams for their supply of water, although surface wells are frequently used. Upon the plateaus and about the foothills springs are often found, some of which might be classed as mineral springs.

Municipal systems.—North Yakima obtains its supply of water from Naches River. The quantity obtained is sufficient for the present and probably for all future needs. The Naches rises in the foothills of the Cascades, and as there are no sources of contamination the quality of water is good. A few wells are used about North Yakima. They range in depth from 18 to 25 feet and are wholly in sand and gravel. The city water supply is used to a very large degree for irrigating, besides serving as a domestic supply.

A sanitary analysis of water from the North Yakima city supply, made on April 8, 1901, by Prof. H. G. Byers, of the University of Washington, resulted as follows:

Sanitary analysis of city water at North Yakima.

[Parts per million.]

Total solids	169.53
Nonvolatile solids	114.85
Volatile solids	54.68
Oxygen consumed	1.79
Chlorine	2.75
Nitrogen as free ammonia	.008
Nitrogen as albuminoid ammonia	.0177
Nitrogen as nitrites	None.
Nitrogen as nitrates	None.

The town of Prosser obtains a water supply from Yakima River. The river gets very low in autumn and may not afford sufficient water to meet the future needs of the town. The water is pumped into a reservoir and is distributed by a gravity system. A few wells have been dug in the region, and these have a depth ordinarily of about 40 feet. They do not enter bed rock, but are wholly in gravel.

Deep wells.—In sec. 4, T. 20 N., R. 12 E., is a deep well owned by F. E. Deeringhoff. It is located on a gentle slope at an elevation of about 1,100 feet above the sea. It was completed in April, 1899. The well was drilled to a depth of 275 feet and then bored for the remainder of the way, a distance of 350 feet. The drilled portion has a diameter of 5⅝ inches, while the bored part has a diameter of 3 inches. Three water-bearing beds were found, the first at a depth of 200 feet, the second at 400 feet, and the third and principal one at 625 feet. The principal water-bearing material is sand. When the well was completed the water rose to a height of 40 feet above the surface, but at present it rises to a height of but 1 foot above the well mouth. The temperature of the water at the surface is 74° F. The water is soft and is sulphur bearing to a slight degree. In casing the well 40 feet of 5-inch, 120 feet of 4-inch, and 80 feet of 3-inch pipe were used. The water is used entirely for irrigation.

In sec. 8, T. 12 N., R. 20 E., J. H. Gano has an artesian well located on a plain. The well was drilled, and has a depth of 826 feet. In the upper portion the diameter is 4 inches, while in the lower portion it is only 2½ inches. Water-bearing beds were found at depths of 300 and 400 feet, besides the principal bed at the bottom. The temperature of the water at the well mouth is 78° F. The water rises 40 feet above the surface. The supply has not decreased since the well was completed. The cost of the well was $1,000. The water is used for irrigating purposes.

In sec. 9, T. 12 N., R. 20 E., E. S. Hill has a deep well, which was completed in 1900. The well was drilled on the slope of a hill, and has a depth of 626 feet. From 200 feet downward several water-bearing beds were found, the principal one being a stratum of sand at the bottom. The well flows, and the supply has not increased or decreased since the well was completed. The temperature of the water at the well mouth is 74° F. The cost was $900. In the well 490 feet of casing has been placed, the upper portion of this having a diameter of 4½ inches and the lower portion a diameter of 3½ inches. The water is used exclusively for irrigation.

In sec. 6, T. 12 N., R. 20 E., is an artesian well owned by J. W. Peck. The well is located in a valley, at a height of about 800 feet above sea. It was completed in 1901 at a cost of $1,200. It has a diameter of 6 inches and a depth of 828 feet. The principal flow of water was found in a sandstone, but other minor water-bearing beds were encountered in drilling. The well is a flowing one, the water rising 4 feet above the surface. The water flows a little less strongly in the summer than in the winter, but on the whole the amount of water remains fairly constant. The temperature of the water at the well mouth is 74° F. The water carries a little iron, magnesia, and sulphur.

In sec. 10, T. 12 N., R. 20 E., Robert Rein has a deep well, which was completed in 1900. The depth of the well is 570 feet, the diameter at the top is 6¼ inches and at the bottom 2⅝ inches. The well is located on a plain at a height of 1,500 feet above the sea. The water rises about 20 feet above the surface, and the supply has been constant since the completion of the well. The temperature of the water at the well mouth is 60° F. The cost of the well was $700. The water is used for irrigating purposes.

In sec. 8, T. 12 N., R. 20 E., is an artesian well owned by Julius Sauve. It is located on a plain at an elevation of 1,155 feet above sea. The diameter of the well in the first portion is 4⅝ inches and in the bottom portion 2 inches. A number of different flows of water were encountered at depths of 790, 861, 876, 890, 907, and finally at the bottom at 1,020 feet. The water rises 80 feet above the surface. The quantity of water has not changed since the well was first drilled. The water at the well mouth has a temperature of 75.2° F. The cost of the well was $1 per foot, or $1,020.

In sec. 8, T. 12 N., R. 20 E., David Walters drilled a well which was completed July 12, 1902. It has a depth of 1,200 feet and a diameter of 5¼ inches. The well is a flowing one. The temperature of the water at the well mouth is 81° F. The cost of the well was $1,600. In casing the well 400 feet of pipe with a diameter of 4 inches and 620 feet of pipe with a diameter of 3¼ inches were used.

Springs.—In T. 9 N., R. 12 E., on Government land, spring water issues as a stream from the base of a bluff of basaltic rock. The water is very cold, free from any odor, and colorless. From the water bubbles of gas are constantly escaping. An analysis of the water made by Prof. H. G. Byers, of the University of Washington, resulted as follows:

Analysis of water from spring in T. 9 N., R. 12 E.

[Parts per million.]

Volatile solids	363.5
Nonvolatile solids	774.5
Total solids	1,138.0
Silica	109.3
Ferric oxide and alumina	82.0
Calcium carbonate	266.4
Magnesium carbonate	177.7
Sodium chloride	213.4
Potassium chloride	38.7
Calcium sulphate	None.
Potassium sulphate	None.

In sec. 9, T. 11 N., R. 15 E., on tribal land belonging to the Yakima Indians, are some warm and cold springs. The water issues as small streams from soil and gravel. About the springs are deposits of reddish matter, presumably iron oxide. The cold springs have a soda taste, and from them all bubbles of gas are constantly escaping. The warm springs are used by the Indians for bathing, and the water is believed by them to possess medicinal value. It is used more for rheumatism than for any other disease. From all of the springs the quantity of flow is constant, no variation being appreciable from season to season.

TABLES OF DEEP WELLS, MUNICIPAL WATER SUPPLIES, AND REPRESENTATIVE SPRINGS.

Deep wells in Washington.

County and post-office.	T.	R.	S.	Name of owner.	Topographic position.	Elevation above sea.
Adams County:						*Feet.*
Cunningham	16	30	22	Thomas and James O'Hair.	Hill	1,278
Ritzville	16	32	33	Northern Pacific Rwy	Valley	1,157
Franklin County:						
Connell	13	32	28	W. T. Braden	Valley	840
Island County:						
Coupeville	....	....	....	E. J. Hancock	Hill	125
Spokane County:						
Hillyard		....	....	Hillyard Town Site Co	Plain	2,000
Stevens County:						
Colville	35	39	9	L. J. Walford	Base of hill	1,590
Thurston County:						
Olympia	....	....	....	State of Washington	Plain	30

Deep wells in Washington—Continued.

County and post-office.	T.	R.	S.	Name of owner.	Topographic position.	Elevation above sea.
Wallawalla County:						*Feet.*
Walla Walla	7	35	27	Blalock Fruit Co	Plain	825
Whitman County:						
Palouse	....	....	....	F. P. Egan	Valley	2,000
Pullman	14	45	5	City of Pullman	Stream bed	2,341
Tekoa	....	....	....	Town of Tekoa	.....do	....
Yakima County:						
North Yakima	20	12	4	F. E. Deeringhoff	Slope	1,100
Do	12	20	8	James H. Gano	Plain	1,100
Do	12	20	9	E. S. Hill	Slope	....
Do	12	20	6	J. W. Peck	Valley	800
Do	12	20	10	Robert Rein	.....do	1,500
Do	12	20	8	J. Saure	Plain	1,155
Do	12	20	8	David Walters	Slope	....

County and post-office.	Date when completed.	Kind of well.	Diameter.	Depth.	Depth to principal source of water.	Water-bearing material.
Adams County:			*Inches.*	*Feet.*	*Feet.*	
Cunningham	1902	Drilled	6	426	426	Rock.
Ritzville	1901	.....do	8	355	300	Very porous rock.
Franklin County:						
Connell	1902	.....do	5	676	660	Porous rock.
Island County:						
Coupeville	1889	Dug	48	125	120	Sand.
Spokane County:						
Hillyard	1900	.....do	44	200	192	Gravel.
Stevens County:						
Colville	1901	Drilled	10 6	700	400	Sandstone.
Thurston County:						
Olympia	1903	.....do	2	152	152	Sand.
Wallawalla County:						
Walla Walla	1903	.....do	6	564	540	Do.
Whitman County:						
Palouse	....	.....do	6	200	150	Do.
Pullman	1890	.....do	6	110	110	Do.
Tekoa	1892	.....do	6	176	176	Porous rock.
Yakima County:						
North Yakima	1899	Drilled and bored.	5⅝ 3	625	625	Sand.
Do	....	Drilled	4 2½	826	820	Do.
Do	1900	.....do	....	626	620	Do.
Do	1901	.....do	6	828	828	Do.
Do	1900	.....do	6¼ 2⅞	570	570	Do.
Do	1900	.....do	4⅝	1,020	1,020	Do.
Do	1902	.....do	3¼	1,200	1,200	Do.

Deep wells in Washington—Continued.

County and post-office.	Other water-bearing beds found.	Distance water rises above surface.	Distance of water from surface.	Temperature of water at well mouth.	Amount of water obtained daily.	Increase or decrease of supply.
Adams County:		*Feet.*	*Feet.*	° *F.*	*Gallons.*	
Cunningham	None		356			Increase.
Ritzville	None		235			Stationary.
Franklin County:						
Connell	None		640	51		Stationary.
Island County:						
Coupeville	Yes		120			Do.
Spokane County:						
Hillyard	None		185		50,000	
Stevens County:						
Colville	Yes					
Thurston County:						
Olympia	Yes	2			8,640	Increasing.
Wallawalla County:						
Walla Walla				67	187,000	Stationary.
Whitman County:						
Palouse	None	Several.		50		Do.
Pullman	None	19		60	180,000	Decreasing.
Tekoa	None	8		76		Stationary.
Yakima County:						
North Yakima	Two	1		74		Decreasing.
Do	Two	40		78		Stationary.
Do	Two	Several.		74		Do.
Do	Yes	4		74		Do.
Do	Yes	20		60		Do.
Do	Yes	80		75		Do.
Do		Several.		81		

County and post-office.	Variation in water level.	Effect of pumping on level of water.	Quality of water.	How water is obtained at surface.
Adams County:				
Cunningham	None	None	Soft	Pumping.
Ritzville	do	Lowers level 10 feet.	do	Do.
Franklin County:				
Connell	do	None	do	Do.
Island County:				
Coupeville		Lowers it slightly.	Hard	Do.
Spokane County:				
Hillyard	Varies during year	Lowers level slightly.	Soft	Do.
Stevens County:				
Colville	None		Iron bearing	
Thurston County:				
Olympia	Varies with tide			Well flows.
Wallawalla County:				
Walla Walla	None			Do.
Whitman County:				
Palouse	do	Lowers level	Hard	Do.
Pullman	do		do	Do.
Tekoa	do	None	Soft	Do.

Deep wells in Washington—Continued.

County and post-office.	Variation in water level.	Effect of pumping on level of water.	Quality of water.	How water is obtained at surface.
Yakima County:				
North Yakima	Varies during year		Sulphur bearing.	Well flows.
Do	None		Soft	Do.
Do	do	None	do	Do.
Do	Varies during year		do	Do.
Do	None	None	do	Do.
Do	Varies during year		do	Do.
Do			Sulphur bearing.	Do.

County and post-office.	Cost.	Cost of pumping machinery.	Size and length of casing.	Use made of the water.
Adams County:				
Cunningham	$1,066	$290	Diameter, 2 inches; length, 423 feet.	Farm supply.
Ritzville	2,500		Length, 240 feet	Locomotives.
Franklin County:				
Connell	3,000		Diameter, 5 inches; length, 100 feet.	Farm supply.
Island County:				
Coupeville	350	150		Do.
Spokane County:				
Hillyard	500	2,500		Town supply.
Stevens County:				
Colville	3,000		Diameter, 10 inches; length, 40 feet.	None.
Thurston County:				
Olympia	152		Diameter, 2 inches; length, 152 feet.	Supply for capitol building.
Wallawalla County:				
Walla Walla	1,800		Length, 540 feet	Irrigation.
Whitman County:				
Palouse	300		Diameter, 5½ inches; length, 150 feet.	Farm supply.
Pullman	450	3,000	Diameter, 6 inches; length, 110 feet.	City water supply.
Tekoa	750	1,000	Diameter, 6 inches	Town supply.
Yakima County:				
North Yakima			Diameter, 5 inches; length, 40 inches. Diameter, 4 inches; length, 120 inches. Diameter, 3 inches; length, 80 inches.	Irrigation.
Do	1,000		Diameter, 4, 3, and 2½ inches.	Do.
Do	900		Diameter, 4½ inches; length, 497 feet.	Do.
Do	1,200			Do.
Do	700			Do.
Do	1,020			Do.
Do	1,600		Diameter, 4 inches; length, 400 feet. Diameter, 3½ inches; length, 620 feet.	Do.

Municipal water supplies in Washington.

Location.	Water-supply system.	Principal source of water.	Other sources.	Sufficient supply for present needs.	Sufficient supply for future needs.
Adams County:					
Ritzville	Yes	Deep wells	None	No	No.
Asotin County:					
Asotin	No	Asotin Creek	Wells and cisterns	Yes	Yes.
Clarkston	Yes	do	None	Yes	Yes.
Chehalis County:					
Aberdeen	Yes	Creek		No	No.
Cosmopolis	Yes	Wells	Creek	Yes	Yes.
Hoquiam	Yes	Hoquiam River	None	Yes	Yes.
Montesano	Yes	Springs	do	Yes	Yes.
Ocosta	No	Wells	Springs		
Chelan County:					
Chelan	Yes	Springs	Lake Chelan	No	No.
Lakeside	No	Lake Chelan	Wells	Yes	Yes.
Wenatchee	Yes	Creek	None	Yes	No.
Clallam County:					
Port Angeles	Yes	Frazer Creek	Wells and springs	No	No.
Port Crescent	No	Wells	Pond	Yes	No.
Clarke County:					
Vancouver	Yes	Springs and deep wells.		Yes	Yes.
Columbia County:					
Dayton	Yes	Springs	None	Yes	Yes.
Cowlitz County:					
Castlerock	Yes	Creek	Wells	Yes	No
Kalama	Yes	Creeks	None	Yes	No.
Douglas County:					
Wilsoncreek	No	Wells	Streams	No	No.
Jefferson County:					
Port Ludlow	Yes	Creek	None	Yes	Yes.
Port Townsend	Yes	Deep wells	Wells and cisterns.	No	No.
King County:					
Auburn	No	Wells	White River	Yes	Yes.
Ballard	Yes	Springs and deep wells.		Yes	No.
Columbia City	Yes	Cedar River	None	Yes	Yes.
Enumclaw	Yes	Mountain streams	Wells	Yes	Yes.
Issaquah	Yes	Springs	do	Yes	Yes.
Kent	Yes	do	None	Yes	No.
Renton	Yes	Spring	Wells	Yes	No.
Seattle	Yes	Cedar River and Cedar Lake.	None	Yes	Yes.
West Seattle	Yes	Springs	do	No	No.
Kitsap County:					
Bremerton	Yes	do	Wells	Yes	Yes.
Charleston	Yes	Springs and creeks	do	Yes	Yes.
Port Blakeley	Yes	Creek		Yes	Yes.
Port Gamble	Yes	Creeks		Yes	Yes.
Kittitas County:					
Clealum	Yes	Springs	Wells	Yes	Yes.
Ellensburg	Yes	Mountain streams	do	No	No.
Roslyn	Yes	Springs and Clealum River.		Yes	No.

Municipal water supplies in Washington—Continued.

Location.	Water-supply system.	Principal source of water.	Other sources.	Sufficient supply for present needs.	Sufficient supply for future needs.
Klickitat County:					
Goldendale	Yes	Spring	None	Yes	No.
Lewis County:					
Centralia	Yes	Wells	Skookum Chuck River.	No	No.
Pe Ell	No	do	Springs	No	No.
Lincoln County:					
Davenport	Yes	Springs	None	Yes	No.
Harrington	Yes	Wells	Springs	Yes	No.
Sprague	Yes	Springs	Wells	Yes	Yes.
Wilbur	Yes	Creek and wells	Springs	Yes	Yes.
Mason County:					
Shelton	Yes	Spring	None	Yes	No.
Okanogan County:					
Loomis	Yes	Sinlahekin Creek	Spring	Yes	Yes.
Pacific County:					
Ilwaco	Yes	Spring		Yes	No.
Southbend	Yes	do	None	Yes	Yes.
Pierce County:					
Buckley	Yes	Well	White River	Yes	Yes.
Carbonado	Yes	Springs	None	Yes	Yes.
Orting	Yes	do	Wells	Yes	No.
Puyallup	Yes	do	None	Yes	Yes.
South Tacoma	Yes	Wells	do	Yes	Yes.
Sumner	Yes	Springs	do	Yes	Yes.
Tacoma	Yes	Clover Creek and springs.	Three wells	No	No.
San Juan County:					
Friday Harbor	No	Wells		Yes	No.
Skagit County:					
Anacortes	Yes	Lake Heart	None	Yes	No.
Hamilton	No	Wells	do	Yes	Yes.
La Conner	Yes	Spring		Yes	
Mount Vernon	Yes	do	None	Yes	Yes.
Snohomish County:					
Arlington	No	Springs and wells	Stilaguamish River	Yes	Yes.
Edmonds	Yes	Springs	Wells	Yes	
Everett	Yes	Wood's Creek		Yes	Yes.
Marysville	No	Wells	None		
Monroe	Yes	Creeks	Wells	Yes	Yes.
Monte Cristo	Yes	Mountain stream	None	Yes	Yes.
Silverton	Yes	do	do	Yes	Yes.
Snohomish	Yes	Pilchuck River	do	Yes	Yes.
Spokane County:					
Cheney	Yes	Lake and wells		Yes	Yes.
Hillyard	Yes	Deep wells	None	Yes	No.
Latah	No	Wells			
Medical Lake	Yes	Clear Lake	Wells	Yes	Yes.
Stevens County:					
Bossburg	Yes	Columbia River	None	Yes	Yes.
Colville	Yes	Spring	Creeks and wells	Yes	No.
Marcus	No	Columbia River	None		
Northport	Yes	Deep Creek		Yes	Yes.
Springdale	Yes	Creek	Wells	Yes	Yes.

Municipal water supplies in Washington—Continued.

Location.	Water-supply system.	Principal source of water.	Other sources.	Sufficient supply for present needs.	Sufficient supply for future needs.
Thurston County:					
Olympia	Yes	Springs	None	Yes	Yes.
Tenino	No	Wells	Spring	Yes	No.
Wallawalla County:					
Waitsburg	Yes	Springs	Creeks	Yes	No.
Walla Walla	Yes	do	Creek	Yes	No.
Whatcom County:					
Blaine	Yes	do		Yes	Yes.
Fairhaven	Yes	Lake Padden	Three creeks	Yes	Yes.
Sumas	No	Wells	Streams	No	No.
Whatcom	Yes	Lake Whatcom	None	Yes	Yes.
Whitman County:					
Colfax	Yes	Palouse River	do	Yes	Yes.
Oakesdale	No	Wells	Springs		
Pullman	Yes	Artesian wells		Yes	Yes.
Tekoa	Yes	do	None	Yes	No.
Uniontown	Yes	Deep well		Yes	Yes.
Yakima County:					
North Yakima	Yes	Naches River	None	Yes	Yes.
Prosser	Yes	Yakima River	do	No	No.

Location.	Quality of water.	Effect of water on the health.	Sources of contamination.	Other sources of supply in contemplation.
Adams County:				
Ritzville	Hard	Good	None	Additional wells.
Asotin County:				
Asotin	Soft	do	do	None.
Clarkston	do	do	do	Artesian wells.
Chehalis County:				
Aberdeen	do	do		Other creeks.
Cosmopolis	do	do	None	None.
Hoquiam	do	do	do	Do.
Montesano	do	do	do	Do.
Ocosta	do	do		Do.
Chelan County:				
Chelan	Hard		Surface drainage	Lake Chelan.
Lakeside	Soft	Good	None	None.
Wenatchee	Contains iron	do	Surface drainage	Do.
Clallam County:				
Port Angeles	Soft	Some ill effects in summer.	Decaying vegetation.	Little River.
Port Crescent	Somewhat salty		None	None.
Clarke County:				
Vancouver	Soft	Good	do	Do.
Columbia County:				
Dayton	do	do	do	Do.
Cowlitz County:				
Castlerock	do	do	do	Do.
Kalama	Hard	do	do	Do.

Municipal water supplies in Washington—Continued.

Location.	Quality of water.	Effect of water on the health.	Sources of contamination.	Other sources of supply in contemplation.
Douglas County:				
Wilsoncreek	Alkaline	Good	None	None.
Jefferson County:				
Port Ludlow	Soft	do		
Port Townsend	do	do	None	Mountain streams.
King County:				
Auburn	do	do		White River.
Ballard	do	do		Seattle water system.
Columbia City	do	do		None.
Enumclaw	do	do	None	Springs.
Issaquah	do	do	do	None.
Kent	do	do	do	Additional springs.
Renton	do	do	do	Cedar River and other springs.
Seattle	do	do	do	None.
West Seattle	do	do	do	Cedar River.
Kitsap County:				
Bremerton	do	do	do	None.
Charleston	do	do	do	Do.
Port Blakeley	do	do	Decaying vegetation.	Do.
Port Gamble	do	do	None	Do.
Kittitas County:				
Clealum	do	do	do	Yakima River.
Ellensburg	Hard	do	do	None.
Roslyn	Soft	do	do	Do.
Klickitat County:				
Goldendale	do	do	do	Additional spring.
Lewis County:				
Centralia	do			None.
Pe Ell	do	Some ill effects.	Sewage	Do.
Lincoln County:				
Davenport	do	Good	None	Do.
Harrington	do	do		
Sprague	do	do	None	Do.
Wilbur	do	do	do	Do.
Mason County:				
Shelton	do	do	do	Other springs.
Okanogan County:				
Loomis	do	do	do	Other creeks.
Pacific County:				
Ilwaco	do	Not good	Decaying vegetation.	None.
Southbend	do	Good	None	
Pierce County:				
Buckley	do	do	do	Do.
Carbonado	do	do	Decaying vegetation.	Do.
Orting	do	do	None	Additional springs.
Puyallup	do	do	do	None.
South Tacoma	Hard	do	do	Do.
Sumner	Soft	do	do	Do.
Tacoma	do	do	do	Additional wells.

Municipal water supplies in Washington—Continued.

Location.	Quality of water.	Effect of water on the health.	Sources of contamination.	Other sources of supply in contemplation.
San Juan County:				
Friday Harbor	Soft	Good	None	
Skagit County:				
Anacortes	do	do	do	Other lakes.
Hamilton	do	do	do	None.
Laconner		do		
Mount Vernon	Soft	do	None	Do.
Snohomish County:				
Arlington	do	do	do	
Edmonds	do	do		
Everett	do	do	None	Do.
Marysville	do	do	do	Lake Stephens.
Monroe	do	do	do	Skykomish River.
Monte Cristo	do	do	do	None.
Silverton	do	do	do	
Snohomish	do	do	do	Do.
Spokane County:				
Cheney	do	do		
Hillyard	do	do		Do.
Latah	do	do	None	Springs.
Medical Lake	Hard	do	do	None.
Stevens County:				
Bossburg	Soft	do	do	Do.
Colville	do	do	do	Do.
Marcus	do	do	do	Do.
Northport	Hard	do	do	Do.
Springdale	Slightly alkaline	do	Surface drainage.	Do.
Thurston County:				
Olympia	Soft	do	None	Do.
Tenino	do	do	do	Do.
Wallawalla County:				
Waitsburg	do	do		Deep wells.
Walla Walla			None	
Whatcom County:				
Blaine		Good		
Fairhaven	Soft	do	None	None.
Sumas	do	do	Surface drainage	Deep well.
Whatcom	do	do	Lumber mills	None.
Whitman County:				
Colfax	do	do		Deep wells.
Oakesdale	do	do	None	None.
Pullman	Hard	do	do	Do.
Tekoa	Soft	do	do	Do.
Uniontown	do	do	do	Do.
Yakima County:				
North Yakima		do	do	Do.
Prosser	Soft	do	do	

Municipal water supplies in Washington—Continued.

Location.	System of waterworks used.	Depth of the wells.	Depth at which water is commonly found.	Character of the water-bearing material.	Depth of water from surface.
Adams County:		*Feet.*	*Feet.*		*Feet.*
Ritzville	Pumping and gravity.	[a] 385 [b] 200	[c] 50	Porous	20
Asotin County:					
Asotin		20–35	25	Gravel and sand	10
Clarkston	Gravity				
Chehalis County:					
Aberdeen	Direct pressure	20–40		Sand	
Cosmopolis	Gravity	10	10	do	([d])
Hoquiam	Pumping and gravity.				
Montesano	Gravity	35	30	Cement and gravel.	25–30
Ocosta		50	40–50	Sand	
Chelan County:					
Chelan	Gravity	Deep.	40–100		([e])
Lakeside		20–40	Level of lake.	Sand	([f])
Wenatchee	Gravity				
Clallam County:					
Port Angeles	do	12–40	10–20	Sand and gravel	10
Port Crescent		16–20	10–12	Sandstone	6
Clarke County:					
Vancouver	Gravity	30–75	25	Gravel	25
Columbia County:					
Dayton	do		25–50	Basalt	
Cowlitz County:					
Castlerock	do		15	Gravel	12
Kalama	do		10	Basalt	10
Douglas County:					
Wilsoncreek		12–54	48	Gravel	
Jefferson County:					
Port Ludlow	Gravity				
Port Townsend	Direct pressure	22–100		Sand and gravel	
King County:					
Auburn		40–50	40	do	
Ballard	Direct pressure	20–160	12–150	do	
Columbia City	Gravity	12–50	10–30	do	
Enumclaw	do		10–30	do	
Issaquah	do	20–30	20	Gravel	2–18
Kent	do		([d])	Sand and gravel	
Renton	do	10–45	10–25	Gravel	6–8
Seattle	do	15–50	12–40	Sand and gravel	10–35
West Seattle	Direct pressure	30–75	50	do	25–70
Kitsap County:					
Bremerton	Gravity		10	Sand	
Charleston	do	20–150	20–150		
Port Blakeley	do		70	Gravel	50
Port Gamble	do				
Kittitas County:					
Clealum	do	10–16	8–12	Sand and gravel	2–8
Ellensburg	do	10–20	10–20	Gravel	([d])
Roslyn	Direct pressure	20–60	12–50	Sandstone	3
Klickitat County:					
Goldendale	Gravity	12–75	20	Gravel	

[a] City well.
[b] Average well.
[c] Varies on lower ground.
[d] Nearly to surface.
[e] No appreciable rise.
[f] Lake level.

Municipal water supplies in Washington—Continued.

Location.	System of waterworks used.	Depth of the wells.	Depth at which water is commonly found.	Character of the water-bearing material.	Depth of water from surface.
		Feet.	*Feet.*		*Feet.*
Lewis County:					
Centralia	Direct pressure	20–30	18	Gravel	6
Pe Ell			8	do	
Lincoln County:					
Davenport	Gravity	20–60	20–40	Basalt	10
Harrington	do	30–100	35	do	20
Sprague	do	20–40	20	Gravel and sand	4–20
Wilbur	do		10–15	Basalt	6–8
Mason County:					
Shelton	do	10–50	10	Gravel	
Okanogan County:					
Loomis	do	20–30	20		
Pacific County:					
Ilwaco	do				
Southbend	do	10–60			
Pierce County:					
Buckley	Direct pressure	20–60	30	Sand	10
Carbonado	Gravity				
Orting	do	6–20	10	Gravel	
Puyallup	Direct pressure	10–20	6–10	Sand	
South Tacoma	do	40–50	40	do	40
Sumner	Gravity				
Tacoma	do	30–100	50	Gravel	30–100
San Juan County:					
Friday Harbor		13–18	10	do	6–8
Skagit County:					
Anacortes	Gravity	10–80	16	do	
Hamilton		10–25	18	Sand and gravel	
Laconner	Gravity			Sand	
Mount Vernon	do	12–14			
Snohomish County:					
Arlington		20–30		Sand and gravel	
Edmonds	Gravity			do	
Everett	do	15–115	100	do	
Marysville			14	Sand	8
Monroe	Gravity	18–50	25	Gravel	8–40
Monte Cristo	do				
Silverton	do				
Snohomish	do		15–55	Gravel	40–45
Spokane County:					
Cheney	Direct pressure	30–50	40	Basalt	
Hillyard	do	190–200	190	Gravel	185
Latah		25–40	35	Rock	
Medical Lake		10–40	15	Basalt	
Stevens County:					
Bossburg	Gravity				
Colville	do	10–30	20	Sand	5–8
Marcus			18–60	Gravel	
Northport	Gravity				
Springdale	do	30–100	40–50	Sand	15–75
Thurston County:					
Olympia	do				
Tenino		25–40	35	Gravel	

Municipal water supplies in Washington—Continued.

Location.	System of water works used.	Depth of the wells.	Depth at which water is commonly found.	Character of the water-bearing material.	Depth of water from surface
Wallawalla County:		*Feet.*	*Feet.*		*Feet.*
Waitsburg	Gravity	40-60	16-40		12-16
Walla Walla	do	10-20		Gravel	
Whatcom County:					
Blaine	do	10-20	10	do	
Fairhaven	do				
Sumas		40-90	40-60	Sand and gravel	
Whatcom	Gravity				
Whitman County:					
Colfax	do	12-120	40	Basalt	
Oakesdale		12-60	10-45	Sand and gravel	10-30
Pullman	Gravity	100-130	100	do	(a)
Tekoa		100-176	100	Basalt	[b]10
Uniontown		175-200		do	
Yakima County:					
North Yakima	Gravity	18-25		Gravel	
Prosser	do	30-40	35	do	35

Location.	Amount of water obtained daily.	Increase or decrease in supply.	Variation in water level.	Effect of pumping on water level.	Other uses besides domestic supply.
Adams County:	*Gallons.*				
Ritzville		Stationary	No	No	Lawns and gardens.
Asotin County:					
Asotin		do	No	Little	Do.
Clarkston					Irrigation.
Chehalis County:					
Aberdeen					
Cosmopolis		Stationary	No	No	Boiler supply.
Hoquiam					Manufacturing.
Montesano		Stationary	Yes	Yes	
Ocosta		do	Yes		
Chelan County:					
Chelan		do	Yes	Yes	Irrigation.
Lakeside		do	Yes	No	Do.
Wenatchee					Lawns and boilers.
Clallam County:					
Port Angeles		Stationary	Yes	Yes	Fire protection and power.
Port Crescent		do	Yes	No	
Clarke County:					
Vancouver		do	Little.	Little	Fire protection, power, etc.
Columbia County:					
Dayton		do	Yes	No	None.
Cowlitz County:					
Castlerock			Yes	Yes	Power.
Kalama		Stationary	Yes	Yes	Irrigation.

(a) A few feet above.

[b] Above.

Municipal water supplies in Washington—Continued.

Location.	Amount of water obtained daily.	Increase or decrease in supply.	Variation in water level.	Effect of pumping on water level.	Other uses besides domestic supply.
Douglas County:	*Gallons.*				
Wilsoncreek			No	No	None.
Jefferson County:					
Port Ludlow					Boiler supply.
Port Townsend	250,000	Stationary	Yes	Yes	None.
King County:					
Auburn					None.
Ballard	300,000	Stationary	No	No	Fire protection.
Columbia City			Yes	No	Irrigation.
Enumclaw		Stationary	Yes	Little	None.
Issaquah		do	Yes	No	Do.
Kent					Boiler supply.
Renton	120,000	Stationary	No	No	Fire protection and boiler supply.
Seattle	22,500,000	do	Yes		Fire, irrigation, etc.
West Seattle			No	No	None.
Kitsap County:					
Bremerton			Yes	Yes	Fire protection and boiler supply.
Charleston		Decreasing	Yes	No	None.
Port Blakeley					Do.
Port Gamble	150,000	Stationary	No	No	Fire protection and boiler supply.
Kittitas County:					
Clealum		do	Yes	No	Irrigation, fire protection and boiler supply.
Ellensburg		do	Yes		Irrigation and boiler supply.
Roslyn		Decreasing	Yes	Yes	Fire protection and boiler purposes.
Klickitat County:					
Goldendale		Stationary	No	No	Irrigation and fire protection.
Lewis County:					
Centralia			Yes	No	None.
Pe Ell		Stationary	Yes	No	Do.
Lincoln County:					
Davenport		do	No	No	Irrigation and fire protection.
Harrington			No	No	Do.
Sprague		Stationary	Yes	No	Do.
Wilbur		do	No	No	Irrigation.
Mason County:					
Shelton		do	Yes		Fire protection.
Okanogan County:					
Loomis					Boiler supply.
Pacific County:					
Ilwaco					None.
Southbend					Boiler supply.
Pierce County:					
Buckley	1,200,000	Stationary	No	No	Fire protection.
Carbonado	20,000				Boiler supply.
Orting			Yes	Very little.	None.
Puyallup			Yes	No	Do.
South Tacoma	150,000	Increasing	Yes	Yes	Boiler supply.
Sumner					
Tacoma	8,000,000	Stationary	Yes	No	Boiler supply, fire protection, etc.

Municipal water supplies in Washington—Continued.

Location.	Amount of water obtained daily.	Increase or decrease in supply.	Variation in water level.	Effect of pumping on water level.	Other uses besides domestic supply.
San Juan County:	*Gallons.*				
Friday Harbor			Yes		Boiler supply.
Skagit County:					
Anacortes		Stationary	Yes	No	Do.
Hamilton		do	Yes	No	None.
Laconner					Do.
Mount Vernon		Increasing	No	No	Fire protection.
Snohomish County:					
Arlington			No	No	None.
Edmonds					
Everett			Yes	Yes	Fireprotection, boiler supply, etc.
Marysville			Yes	No	None.
Monroe			Yes	Yes	Do.
Monte Cristo					Boiler supply and concentrator.
Silverton					Concentrator.
Snohomish			No		Boiler supply.
Spokane County:					
Cheney			No	No	Fire protection.
Hillyard		Stationary	Yes	Yes	Irrigation.
Latah					
Medical Lake					
Stevens County:					
Bossburg					
Colville		Stationary	No	No	None.
Marcus					
Northport					
Springdale			No	No	Boiler supply.
Thurston County:					
Olympia	3,000,000				Fireprotection, boiler supply, etc.
Tenino		Stationary	Yes	Yes	None.
Wallawalla County:					
Waitsburg					Water motor.
Walla Walla			Yes		Fire protection.
Whatcom County:					
Blaine		Increasing	Yes		Boiler supply.
Fairhaven					Boiler supply and fire protection.
Sumas		Stationary	No	No	None.
Whatcom					Boiler supply and fire protection.
Whitman County:					
Colfax					Do.
Oakesdale		Stationary			Fire protection.
Pullman	300,000	Decreasing	No	Yes	Boiler supply and fire protection.
Tekoa		Stationary	No	No	None.
Uniontown		do	No	No	Street sprinkling.
Yakima County:					
North Yakima					Irrigation.
Prosser			No	No	Do.

Representative springs in Washington.

County and post-office.	T.	R.	S.	Owner of spring.	Topographic position.	Quantity of flow.
Adams County:						*Gallons.*
Washtucna	15	36	28 33	G. W. Bassett	Base of bluff	[a] 40
Chelan County:						
Wenatchee	22	19	24	George Brisson	do	[a] 8
Clark County:						
Vancouver	1	2	3, 4	Vancouver Waterworks Co.	Hillside	[b] 1,750,000
Columbia County:						
Dayton	9	39	3	City of Dayton	do	
King County:						
Berlin		11		Everett Bottling Works.	do	[a] 3
Issaquah	24	6	27	Gilman Water Co.	Head of canyon	
Kent	22	5	19	Town of Kent	Base of steep hill.	[b] 500,000
McCain	13	26	29	T. G. McCain	Foot of mountain.	[a] 3
Renton	28	5	20	Seattle Electric Co.	Hillside	[b] 183,018
Klickitat County:						
Glenwood	9	12		United States	Valley	
Do	6	13		do	Base of bluff	
Goldendale	4	14			In canyon	
Lincoln County:						
Davenport	25	37	21	Town of Davenport.	Base of bluff	[b] 360,000
Harrington	23	36	34	J. L. Ball		[a] 2
Do	23	36	14	J. E. Ludy	Deep valley	
Do	23	36	9	L. T. Luper	Valley	[b] 28,800
Sherman	29	33	25	H. B. Fletcher	do	
Mason County:						
Shelton	20	4	12	Town of Shelton	Hillside	
Pierce County:						
Carbonado	18	6	4	Carbon Hill Coal Co.	do	
Orting	19	5	29	Orting Light and Water Co.	do	
Puyallup	20	4	32	City of Tacoma	Base of bluff	[b] 18,000,000
Skamania County:						
Cascades	2	7	16	Thomas Moffatt	Hillside	[b] 25,000
Spokane County:						
Latah	21	45	26	William Forthman.	Base of bluff	[b] 720
Stevens County:						
Colville				J. U. Hofeteta	Valley	
Wallawalla County:						
Walla Walla				City of Walla Walla.	do	
Yakima County:						
Fort Simcoe	11	15	9	Yakima Indians	Narrow valley	[b] 57,600

[a] Miner's inches [b] Daily.

Representative springs in Washington—Continued.

County and post-office.	Variation in flow.	Taste.	Temperature.	Quality of water.	Kind of rock.
Adams County:			°F.		
Washtucna	None	Pleasant	40	Soft	Basalt.
Chelan County:					
Wenatchee	Decreases in flow in autumn.	do	55	Hard	Do.
Clarke County:					
Vancouver	Varies slightly	do		Soft	
Columbia County:					
Dayton	Decreases in summer	do		do	
King County:					
Berlin	None	Soda		Alkaline	Syenite.
Issaquah	do.	Pleasant		Soft	
Kent	Decreases in summer	do		do	
McCain	None	Sulphur	122	Sulphur	Granite.
Renton	Diminishes in autumn	Pleasant		Soft	
Klickitat County:					
Glenwood	None	do			Basalt.
Do	do	Unpleasant	76	Cnarged with gas.	Do.
Goldendale	do	Mineral	100	do	Do.
Lincoln County:					
Davenport	Decreases in summer	Pleasant		Soft	Granite.
Harrington	None			do	
Do	Decreases in summer	Pleasant	45	do	Basalt.
Do	None	do		do	
Sherman	do	do		do	
Mason County:					
Shelton	do	do		do	
Pierce County:					
Carbonado	Decreases in summer	do	54	do	
Orting	None	do		do	
Puyallup	do	do		do	
Skamania County:					
Cascades	do	Sulphur	96	Sulphur, iron, etc.	
Spokane County:					
Latah	Maximum in spring	Pleasant		Soft	
Stevens County:					
Colville	None	do		do	
Wallawalla County:					
Walla Walla	do	do		do	
Yakima County:					
Fort Simcoe	do	Soda	Warm	Charged with gas.	

Representative springs in Washington—Continued.

County and post-office.	Seeps or stream.	Deposits of mineral matter about spring.	Use of water.	Improvements at spring.	Improvements contemplated.
Adams County:					
Washtucna	Stream	None	Town supply and irrigation.	None	None.
Chelan County:					
Wenatchee	do	do	Domestic and irrigation.	do	Do.
Clarke County:					
Vancouver	do	do	City water supply.	do	Do.
Columbia County:					
Dayton	Seeps out	do	do	do	Do.
King County:					
Berlin	Stream	Iron	None so far	do	Hotel.
Issaquah	do	None	Town supply	do	None.
Kent	do	do	do	do	Storage reservoir.
McCain	Seeps out	do	Medicinal and bathing.	Hotel	Addition to hotel.
Renton	do	do	Town supply	None	None.
Klickitat County:					
Glenwood	Stream	Iron	None	do	Do.
Do	do	Yes	do	do	Do.
Goldendale	do	Iron	do	do	Hotel and a bath house.
Lincoln County:					
Davenport	do	None	City supply	do	None.
Harrington		do	Domestic		
Do	Stream	do	do	None	Do.
Do	do	do	do	do	Do.
Sherman	do	do	do	do	Do.
Mason County:					
Shelton	do	do	Town supply	do	Do.
Pierce County:					
Carbonado	do	do	do	do	Do.
Orting	do	do	Domestic	do	Do.
Puyallup	do	do	City supply	do	Do.
Skamania County:					
Cascades	Seeps out	do	Medicinal, domestic	Hotel and bath house.	New hotel and bath house.
Spokane County:					
Latah	Stream		Domestic	None	None.
Stevens County:					
Colville	Seeps out	do	Town supply	do	Do.
Wallawalla County:					
Walla Walla	Stream	do	City supply	do	Do.
Yakima County:					
Fort Simcoe	Seeps out	Iron	Bathing	do	Do.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, Director

UNDERFLOW TESTS
IN THE
DRAINAGE BASIN OF LOS ANGELES RIVER

BY

HOMER HAMLIN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
RECLAMATION SERVICE,
Washington, D. C., March 28, 1904.

SIR: I have the honor to transmit, for publication in the series of Water-Supply and Irrigation Papers, a manuscript entitled "Underflow Tests in the Drainage Basin of Los Angeles River," by Mr. Homer Hamlin.

The report describes the conditions under which ground water usually occurs in arid regions and the fluctuations in the water level due to rainfall and other causes. The methods used in obtaining this information are of interest, and the paper will contribute valuable material to the important subject of underground waters and their use in the arid regions.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

UNDERFLOW TESTS IN THE DRAINAGE BASIN OF LOS ANGELES RIVER.

By Homer Hamlin.

INTRODUCTION.

The purpose of this report is to assemble in one publication the results of a series of underflow tests made in the drainage basin of Los Angeles River in 1902 and 1903 by the United States Geological Survey.

This report briefly describes the conditions under which ground water usually occurs, especially in arid regions, and the fluctuations in its water level due to rainfall and to sinking flood waters.

The method of testing used was invented by Prof. Charles S. Slichter, and is fully described in "The Motions of Underground Waters."[a] Up to the present few investigators have used this method.

An attempt has been made to describe briefly the method of sinking test wells and the machinery designed and used during this investigation. The various devices used in testing and the arrangement of the instruments, the methods of testing found most satisfactory, the results obtained at each of the testing stations, and the amount of underflow supposed to pass the Huron street section. are fully described.

GROUND WATER.

By ground water is meant water percolating beneath the surface of the earth. The original source of all ground water is rainfall. Part of the rain soaks into the ground and percolates downward until it reaches a level where the interstices of the rocks, sand, and gravel are already saturated; another part is absorbed by growing plants or evaporated from the surface of the ground; and still another part runs off in surface streams.

---

[a] Slichter, Charles S., The motions of underground waters: Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902.

WATER TABLE.

The upper surface of the water-soaked zone in pervious ground is called the water table or water plane. From the surface of the ground to the water table the ground is damp but not saturated, and all contributions of surface water continually tend to sink downward, while below this level the ground is completely saturated; that is, all of the open spaces between the rock particles are full of water. The water table is the level at which water is struck in a well. In artesian belts the water is under pressure, being confined by overlying impervious strata, and when such strata are pierced it rises to the level of the outcrop of the water-bearing formation. The water table is not a level plane like the surface of a lake, except rarely in inclosed basins, but usually has a slope toward the main drainage lines of the region, to which the ground water slowly flows. The slopes usually follow in a general way the surface topography, but are much flatter.

FLUCTUATIONS OF WATER TABLE.

As the ground below the water table is completely saturated, any contributions of water from the surface must result either in raising the water table or in a lateral movement of the ground water toward some outlet. Usually both phenomena occur, the lateral flow being a result of and following the rise in the water table. In humid regions the supply from rainfall is so nearly constant throughout the seasons that the position of the water table is practically fixed, and the rate of lateral movement does not change appreciably from year to year. In arid regions much of the ground water under the plains and valleys is supplied by the streams which pour down from adjacent mountain ranges. When such streams leave the mountain canyons they soon sink in their débris cones of sand, gravel, and bowlders; in such localities the water table is sometimes 200 or 300 feet below the surface. When in flood such streams discharge enormous quantities of water, which sinks and is added to the ground water of the region. The immediate result is the raising of the water table, often 25 to 50 feet, over the region where the sinking occurs. The ground water afterwards flows outward in a generally horizontal direction from these regions and the water table is gradually lowered. In arid regions the water table rises sometimes many feet during rainy seasons and gradually sinks in dry years or during the dry season.

VELOCITY OF UNDERFLOW.

The slowly moving ground water beneath a stream bed or valley is usually designated "the underflow." In order to estimate accurately the amount of ground water passing a given section, it is necessary to know, among other factors, the rate of movement or velocity of the underflow through the pervious beds below. This is conveniently measured by the method invented by Professor Slichter.[a] Briefly the method is as follows:

A group of four or five wells arranged as shown in figs. 9 and 10 is sunk at the locality where the underflow is to be tested. Well A is placed upstream, or in the direction from which the underflow is supposed to come, and the wells B, C, D, and E are spaced downstream at a uniform distance from well A. All of these wells are of small diameter (drive pipe, 1¼ to 2 inches) and have from 4 to 8 feet of perforated screen, usually ordinary well points, at the lower end. These perforations allow the percolating water to pass through the pipe driven into the pervious stratum to be tested. The upper well, A, is charged with a chemical, usually sal ammoniac (NH_4Cl), which dissolves in the water passing through the well and is carried along by the underflow to one or more of the lower wells—which ones depends upon the direction of the underflow. The arrival at one of the lower wells of water containing sal ammoniac in solution is detected by means of electrical instruments.

METHODS AND APPARATUS USED IN UNDERFLOW TESTS.

In September, 1902, the writer was placed in charge of experiments to determine, if possible, the amount of underflow passing through the narrows of Los Angeles River at Huron street, Los Angeles, Cal.

Velocity measurements were begun under direction of Prof. Charles S. Slichter, with the apparatus invented by him. As the work progressed and tests at greater depths were made it was found necessary to modify this apparatus to suit local conditions.

LOCATION OF TEST WELLS.

The first step in testing the velocity of an underflow is to determine, approximately, the direction in which the underflow moves, and the second is to drill the test wells for measuring it. If the locality chosen is in a narrow valley or canyon bounded by rock walls, it is obvious that the underflow must be down the general trend of the valley. If, however, the tests are to be made in a wide valley or plain, it is advisable to ascertain the extent and slope of the water table in the vicinity.

If there are wells near, they should be located by some of the ordinary methods of surveying, and levels referred to some permanent bench mark should be run and the surface elevation at each well determined. The depth to water should be measured and the elevation of the water table computed. It is sometimes necessary to sink additional test wells, which should be located as just described. The data should be platted on a map and contours, or lines of equal elevation, of the water table drawn, and the slope of the water table determined. The movement of the ground water in general is down the slope of the water table.

---

[a] Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, pp. 48-51.

Fig. 21 (p. 42) is a map of the narrows of Los Angeles River at Huron street, Los Angeles, Cal., showing the extent and slope of the water table at that locality. The broken contour lines show the form of the water table in December, 1902; the dotted contour lines the form in June, 1903. The rise in the water table was due to the sinking flood waters of the Arroyo Seco, which enters Los Angeles River a short distance below. Its channel is usually a dry wash of sand and bowlders, but was in flood during March and April, 1902, and the map shows plainly the sudden rise in the ground water due to the sinking of the storm waters.

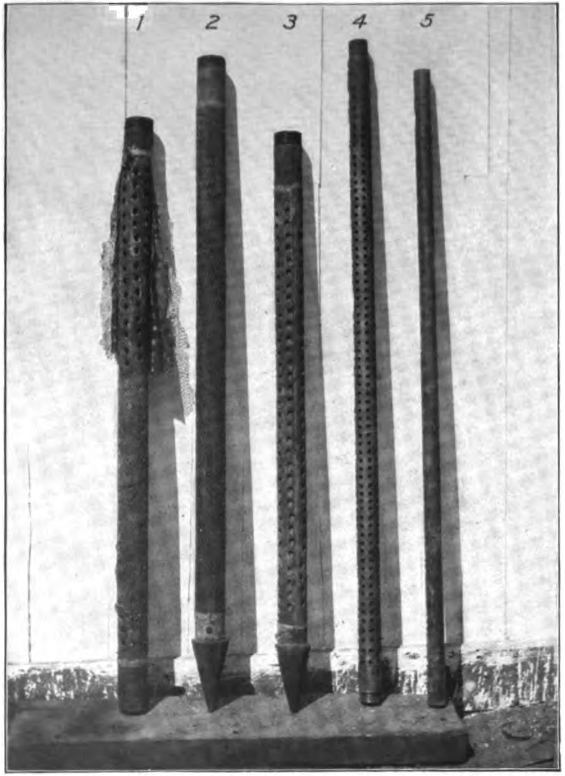
A practical conclusion to be drawn from this map is that in order to avoid the disturbing influence of the fluctuations of a tributary stream the test wells should be located a considerable distance either above or below the mouth of such a stream.

When the slope of the water table and the approximate direction of the underflow have been ascertained, wells for testing the velocity should be sunk in groups arranged as shown in figs. 9 and 10 (pp. 24 and 25). They may be sunk by any of several methods, depending on the locality, depth to the water table, coarseness of material, etc.

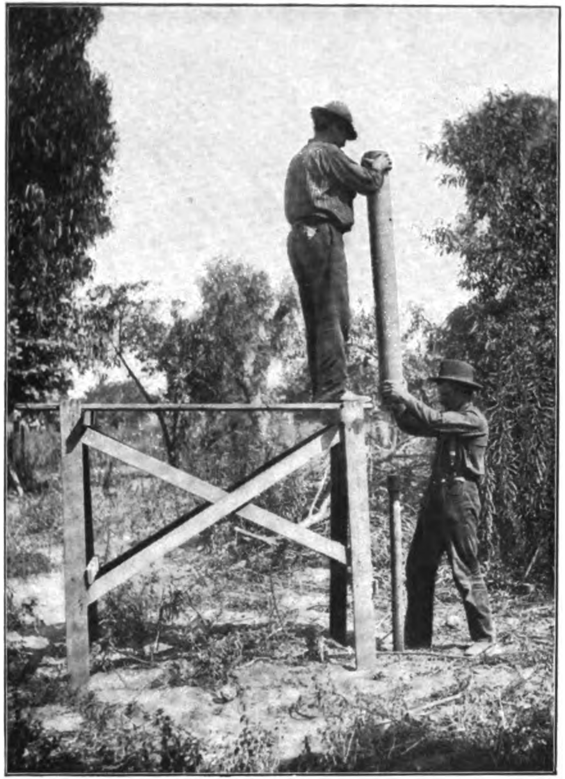
HAND DRIVING.

For shallow wells in unconsolidated material ordinary well points, as shown in figs. 2 and 3 of Pl. I, *A*, may be used. These are screwed on a length of standard or extra strong wrought-iron pipe and simply driven into the porous strata. Two men using a heavy wood maul, as shown in Pl. I, *B*, can drive such wells to a considerable depth, and, in such cases, this is a rapid and economical method. It is not possible, however, to collect samples of the material penetrated, and the porosity must be estimated from the amount of water yielded when the wells are pumped. This method was used in the first velocity test made in Los Angeles River, but was abandoned as unsatisfactory when deeper tests were attempted.

A portable hand rig is sometimes used to drive well points. Ordinarily two men can drive as many feet a day with a maul as with the hand rig in unconsolidated sands, unless the wells are deep. When used in combination with the hydraulic-jet method of sinking wells, such a rig will sink a pipe to a considerable depth, depending on the material penetrated, but when the material is coarse a point is soon reached beyond which it is impossible to drive any style of small pipe, as it is telescoped or battered by the hammer.



A. WELL POINTS



B. DRIVING WELL POINTS.

WELL-DRILLING RIG.

When wells are to be sunk to a considerable depth, 100 to 150 feet for instance, in very coarse material, some kind of machinery is necessary. A rapid and economical method is a modification of the hydraulic-jet process of deep-well drilling by combination with driving. This method consists of three distinct processes—(1) driving the pipe; (2) chopping up and washing out the sand and gravel that enters the bottom of the pipe as it is driven downward; (3) turning or rotating the pipe to keep the hole straight and to reduce the frictional resistance to driving. A rig equipped for this work, with the machinery assembled, is shown on Pl. II. It consists of the derrick for hoisting the heavy drivepipe, a hammer for driving the pipe, wash rods and chopping bit for hydraulicking, a pump for forcing water down the wash rods under pressure, and a rotator for turning the pipe. The whole is driven by a gasoline engine with a hoisting attachment. This machinery was designed to meet the local conditions of sinking wells to a depth of 100 to 150 feet in very coarse sharp sand, gravel, and bowlders. It has proved economical and satisfactory in actual use for several months.

MACHINE DRILLING.

When starting a well, a hole is first dug to a depth of 4 or 5 feet and a 10-foot length of drivepipe with a shoe firmly screwed on is inserted vertically, passing up through the rotator (a), as shown on Pl. III, *A*. It must be plumbed carefully, for if it is not driven straight the wells will not be properly spaced at the bottom, and this will introduce errors into the velocity measurements. About 13 to 15 feet of wash rod, with a chopping bit attached, is then inserted in the drivepipe, projecting about 3 feet above the top. The drive head (c) is then screwed on the drivepipe with the wash rods projecting up through the hole in the center.. The buffer block (e) and hammer (f) should then be slipped over the wash rods which serve as a guide for the hammer, and the water swivel (g), with the hose attached, should be screwed to the top of the wash rods. The ropes for hoisting and driving and the sprocket chain for driving the rotator, etc., are attached as shown on Pl. II, *A*, and Pl. III, *A*.

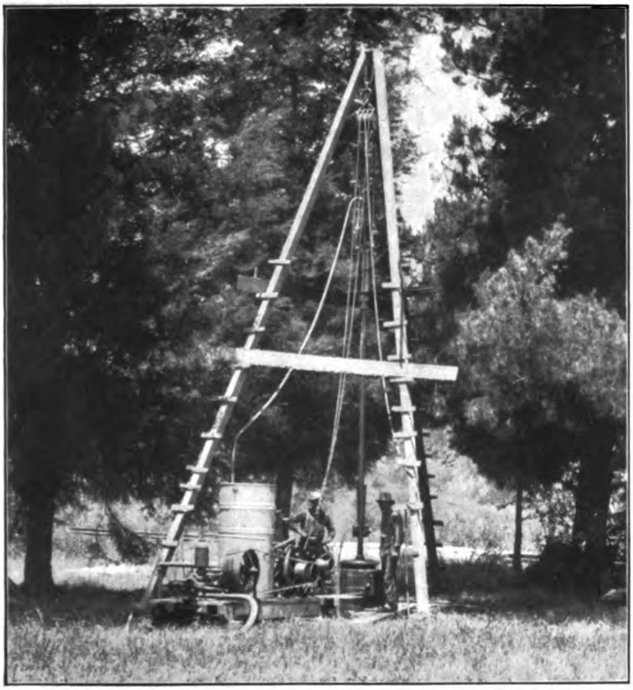
The rig is operated as follows: Drive the pipe a few feet by tapping lightly with the hammer, then start the pump and force water down the wash rods and through the chopping bit. The rods should be churned up and down like a churn drill until the drivepipe is clear of sand to the bottom of the shoe. The chopping bit can be operated with, or independent of, the rest of the driving apparatus by a line passing over the middle sheave of the hoisting block. When the well is shallow the chopping can be done by hand, but when deep it is necessary to use the winch or winding drum on the engine. The water swivel is made with a projecting base larger than the hole through the hammer (see fig. 7). By means of this device it is possible to drill with the chopping bit and at the same time drive the pipe with the hammer. The length of wash rods is so adjusted that the water swivel is 6 inches to 1 foot above the top of the hammer, when it rests on the drive head. As the ordinary stroke of the hammer is 1 to 2 feet, the wash rods will be raised from 6 inches to 1 foot at each stroke. When the hammer is dropped the rods drop with it until the chopping bit strikes the sand in the hole, while the hammer still falls and almost instantly strikes the drive head. This is done automatically, the only attention required from the driller being the gradual lowering of the wash rods as the pipe is driven downward. The water which is forced out in jets through the chopping bit washes the pulverized sand and gravel up through the drivepipe to the surface. The drivepipe should be turned from three to five times per minute by an ordinary rotator such as is used with hydraulic-well rigs. The rotator should be run from the engine by a sprocket chain passing over sprocket wheels, as shown on Pl. II, *B*, and Pl. III, *A*. When the wells are shallow two men with chain tongs can usually turn the pipe.

This method is particularly adapted to sinking wells in coarse sand and bowlders. The drivepipe should be double, extra-strong, steel pipe to secure the strength and stiffness necessary to prevent bending when forced through coarse materials, and its internal diameter should be at least 2¼ inches. It is sometimes very difficult to pull a long string of drivepipe, especially to start it. The only practicable way is to use jackscrews, as shown on Pl. III, *B*, or use block and tackle with the engine at the same time turning the pipe with the rotator. Below is a more detailed description of machinery used.

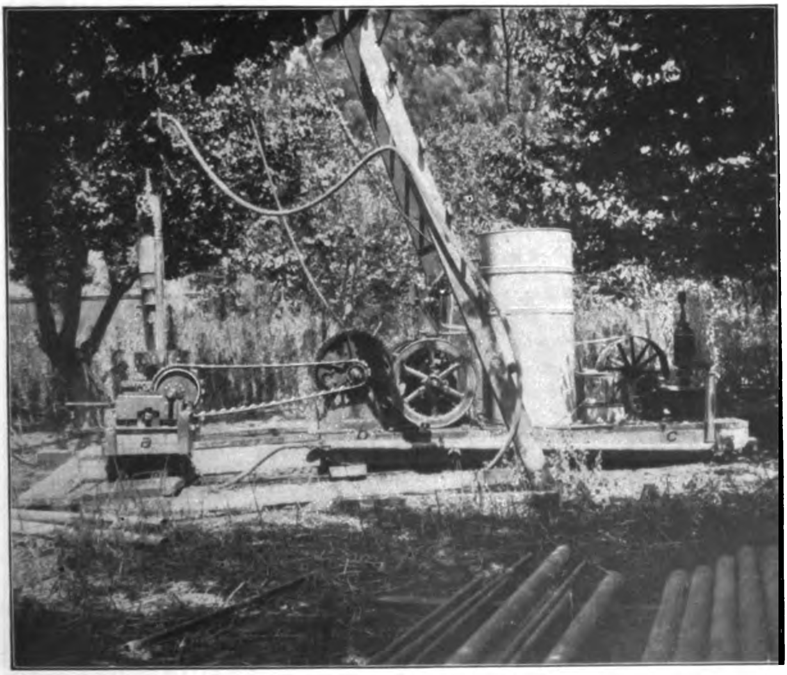
APPARATUS.

ENGINE.

In the selection of an engine, consideration must be given to the cost of fuel, transportation facilities, weight of machinery, etc. When fuel is expensive and water scarce, a gasoline engine will be found economical. For ordinary drilling when the depth of the wells does not exceed 150 or 200 feet, a 6 to 8 horsepower engine will furnish the necessary power. A very convenient type of engine is shown on Pl. II, *B*. It is a vertical gasoline engine geared to a hoisting drum, which is controlled by means of a friction clutch and brakes. The drum is used to raise the hammer and wash rods, for hoisting pipe, etc. From ten to twenty blows per minute can be struck with the hammer in driving pipe. The small winch on the engine is used for pulling



A. WELL-DRILLING RIG.



B. WELL-DRILLING MACHINERY.

pipe, moving heavy weights, moving the engine, etc. The engine is belted to a force pump, which supplies water for hydraulicking, and is connected to the rotator by a sprocket chain. The engine shown in the cut is but 3 horsepower and is too light for deep wells, but has proved very economical in fuel consumption, using but 3 to 4 quarts of gasoline per day in ordinary drilling; in addition it has required but little attendance, is light, and easily moved.

PUMP.

The pump should be a suction force pump, capable of delivering water under a pressure as high as 150 pounds per square inch, with a discharge of 20 to 50 gallons per minute. It should be provided with a safety valve to prevent excessive pressure. The pump must be able to draw a supply from one to two driven wells, when the water table is within reach. In other cases it will be necessary to haul water for hydraulicking—an expensive and troublesome method.

Connection between the pump and the wash pipe, as shown in Pl. II, *A* and *B*, and Pl. III, *A*, is made by means of 25 to 30 feet of flexible hose of good quality to withstand high pressure. Ten to 15 feet of 2-inch suction hose will be needed to connect the pump with the drive wells from which the wash water will usually be pumped.

LIGHT DRIVEPIPE.

For shallow wells driven by hand in unconsolidated material the ordinary standard or extra-strong pipe will answer for drivepipe. It can usually be pulled and used several times. The outside couplings of such pipe greatly increase the frictional resistance in driving and pulling, and a considerable percentage of pipe is sure to be left in the ground. Extra-strong pipe is sometimes fitted with flush-joint couplings, but so much metal is cut away at the joint that they are frail and will not withstand hard driving, breaking at the joint when the pipe does not go down straight.

HEAVY DRIVEPIPE.

For deep wells the drivepipe should be what is known to the trade as double-extra-strong steel pipe with joints flush inside and out. The inside diameter of the drivepipe must be at least 2¼ inches. The nearest commercial size to this is known as 3-inch pipe; its actual diameter is 3½ inches outside and 2.284 inches inside, the thickness of its shell 0.608 inch and its weight 18.56 pounds per linear foot. Rings of tough Norway iron of the same diameter and thickness as the pipe, and 6 or 8 inches long, should be welded on both ends of each length of pipe, in which the flush-joint coupling should be turned. A taper thread with butt joints, as shown in fig. 1, has been found satisfactory and stands much hard usage. This form of thread has the advantage of a firm bearing throughout its entire length when it is screwed up tight. The pipe should be finished in lengths of exactly 10 feet with a few additional short lengths of 5 feet. A 1½ to 2 foot length (*b* on Pl. III, *A*.) should also be provided with a 1½-inch hole drilled through it about midway of its length to allow the wash water and sand to run out; the drive head should be screwed on the upper end of this short length. Such a drivepipe is stiff and heavy enough to stand repeated blows from the hammer. The fact that there are no outside couplings make it far easier to drive and pull than the ordinary pipe.

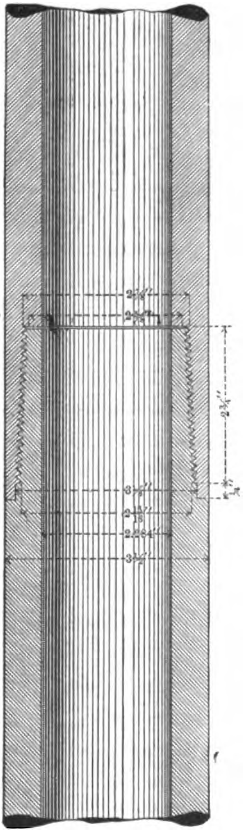


FIG. 1. Heavy drivepipe.

SHOE.

The lower end of the drivepipe must be protected from injury by a shoe. The form shown in fig. 2 has been found satisfactory. It should be turned out of tough steel, the outside diameter being a trifle greater than the outside of the drivepipe, and the inside diameter the same. If it is to be used with a rotator the cutting edge should be notched and well tempered, as it will then cut its way downward more readily. The threads should be the same as on the drivepipe, so that it will fit on any length.

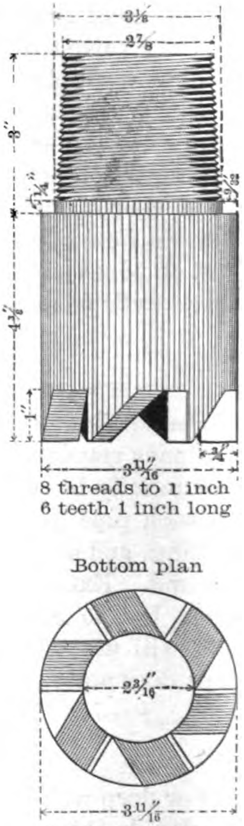
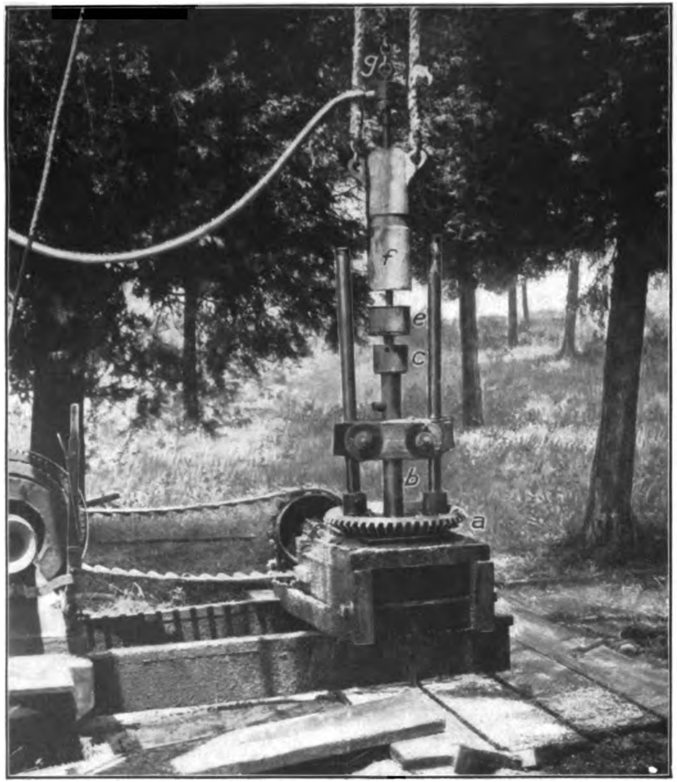


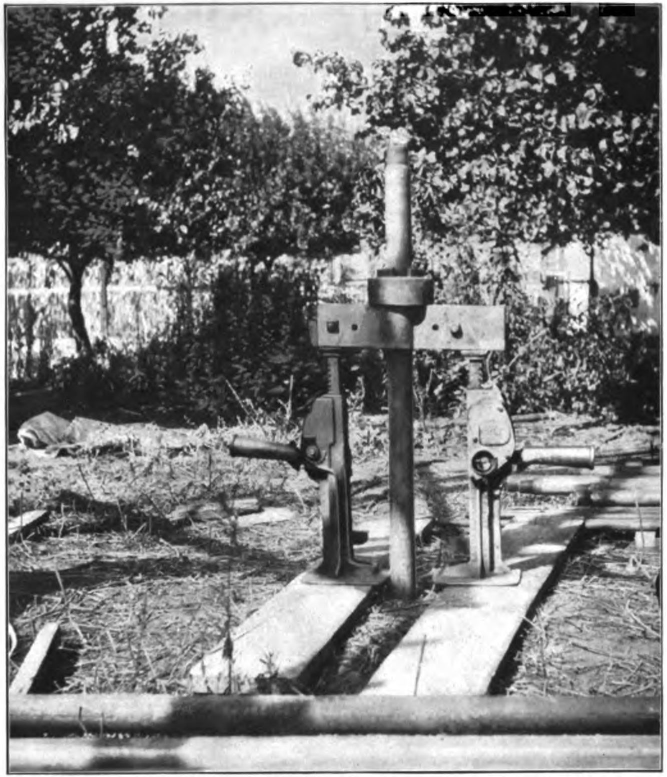
FIG. 2.—Drive shoe.

DRIVE HEAD.

The drive head, as shown in fig. 3, should be made of steel, accurately turned to fit the drive pipe on which it is screwed, and strong enough to withstand long-continued driving. The wash rods pass up through the hole in the center of the head, serving as a guide for the hammer (see *c* on Pl. III, *A*). The four holes drilled in the side are



A. ROTATOR AND DRIVING MACHINERY.



B. JACKSCREWS.

sockets for rods used in screwing on the head or in handling the pipe. A bail for lifting can be sprung into these holes, if desirable, but an eyebolt passing through the hole in the center and loosely fastened with a nut and washer inside the drive head will act as a swivel and be found stronger and more convenient when pulling pipe, hoisting, etc.

BUFFER BLOCK.

A wooden block should be placed between the hammer and the drive head to prevent the destruction of both. A convenient form is shown in fig. 4. It is simply an oak or other hardwood block with the grain of the wood vertical, securely bound with an iron band. A hole should be bored through the middle and the block may then be slipped over the wash rods and rest on the drive head, as shown at e on Pl. III, *A*.

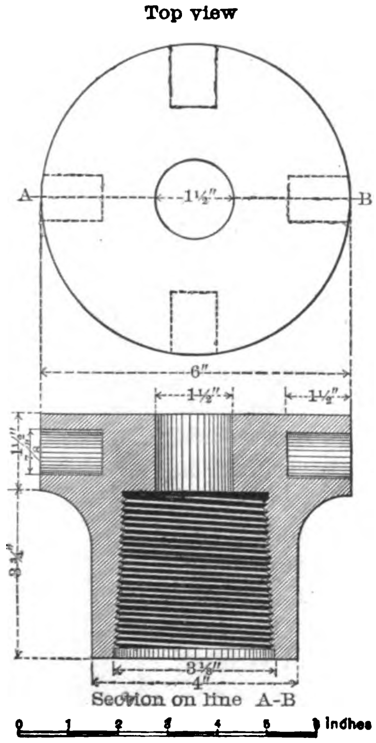


FIG. 3.—Drive head.

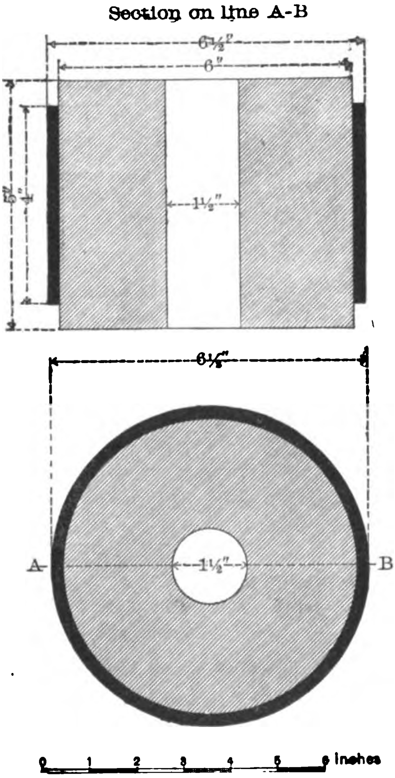


FIG. 4.—Buffer block.

HAMMER.

A hammer of the form shown in fig. 5 requires no guides, but slides up and down on the wash rods. It may be made of cast iron with projecting ears for attaching the hoisting ropes. When it is necessary to add a length of drive pipe, the hammer can be raised off the wash rods, swung to one side, and lowered to the ground. It is raised and lowered independently of the wash rods by means of two ropes, which pass up through the outside sheaves of the hoisting block at the apex of the derrick and thence to the winding drum of the engine, as shown on Pl. II, *A*, and at f on Pl. III, *A*.

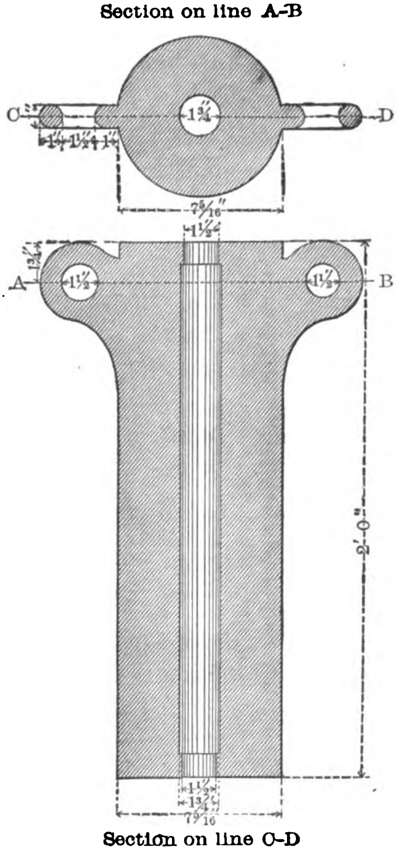
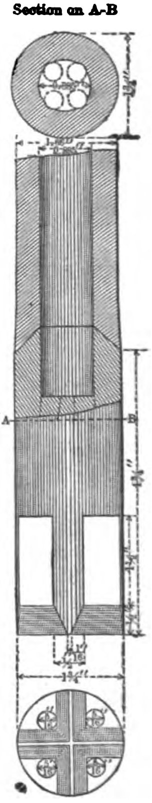


FIG. 5.—Hammer.

WASH RODS.

The wash rods should be made of what is known as double-extra-strong 1-inch pipe, the diameter being 1.315 inches outside and 0.587 inch inside, the thickness of the shell 0.364 inch, and the weight 3.65 pounds per linear foot. The rods should have rings of Norway iron on each end and the same style of taper thread as the large drive pipe shown in fig. 1. When finished, the rods should be exactly 10 feet in length, but several 5-foot and 2-foot pieces should also be on hand. If deep wells are to be drilled, heavier wash rods will be necessary. This will require larger holes than those figured in the drive head, buffer block, and hammer.



Bottom plan showing beveled edges of chopping bit.

FIG. 6.—Chopping bit.

CHOPPING BIT.

The chopping bit should be made of best tool steel. A drawing of the bit in use is shown in fig. 6. It should be securely welded to a 5-foot length of wash rod instead of being screwed to it, otherwise when drilling in coarse material or bowlders it will probably be broken off and lost in the well. The cut shows the bit welded to a length of double-extra-strong 1¼-inch pipe, commercial size.

The edges of the star bit should not be drawn down too thin, and must be well tempered to withstand hard usage, for when drilling the impact of the heavy string of wash rods, when dropped several feet, must be borne by the chopping bit. The holes through the bit should be of ample size to deliver enough water to raise the pulverized sand and gravel to the surface and still must be small enough to give the issuing jet a high velocity.

WATER SWIVEL.

A swivel connection between the hose and the wash rods is necessary to permit turning the chopping bit, making connections, etc. The form shown in fig. 7 has been found convenient. It should be strong and well made, as the hammer engages with the lower part of the swivel in raising the wash rod. As sand and gravel in the drive pipe sometimes pack around the drill and rods, the pull on the swivel may be considerable, perhaps enough to stop the engine, in which case the wash rods must be jarred loose by upward blows with the hammer.

DERRICK.

The derrick may be made of three timbers, about 4 by 6 inches, and 30 to 36 feet long, as shown in Pl. II, *A*. Holes are bored through the top and the timbers loosely connected by a 1-inch bolt, from which is suspended a long clevis, to which the hoisting blocks are attached. Such a tripod can be quickly raised, lowered, or adjusted over a well. Slats nailed on the timbers serve as a ladder for reaching the top.

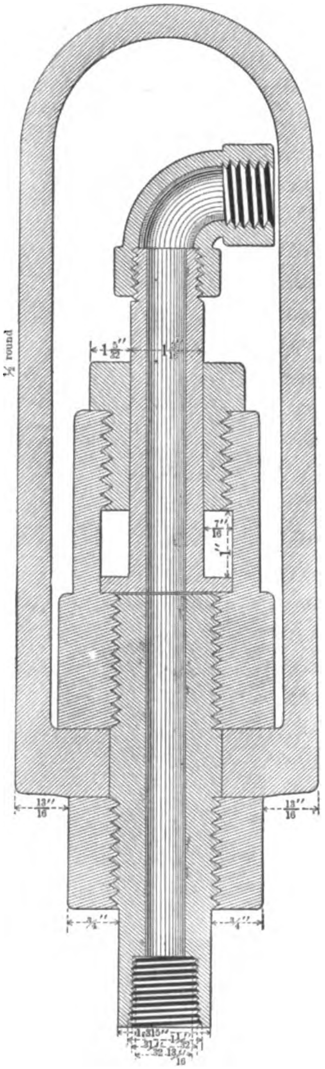


FIG. 7.—Water swivel.

BLOCKS.

The lines from the hammer should be run up over the outside sheaves of a triple block, and then to the winding drum of the engine, as shown in Pl. II, *A*. The line from the wash rods is run over the center sheave and then fastened to a cleat on one leg of the tripod. By this arrangement the rods can be easily raised or lowered by hand, or suspended at any height.

A double block should be provided for use with the triple block in pulling the drive pipe, moving the engine, etc.

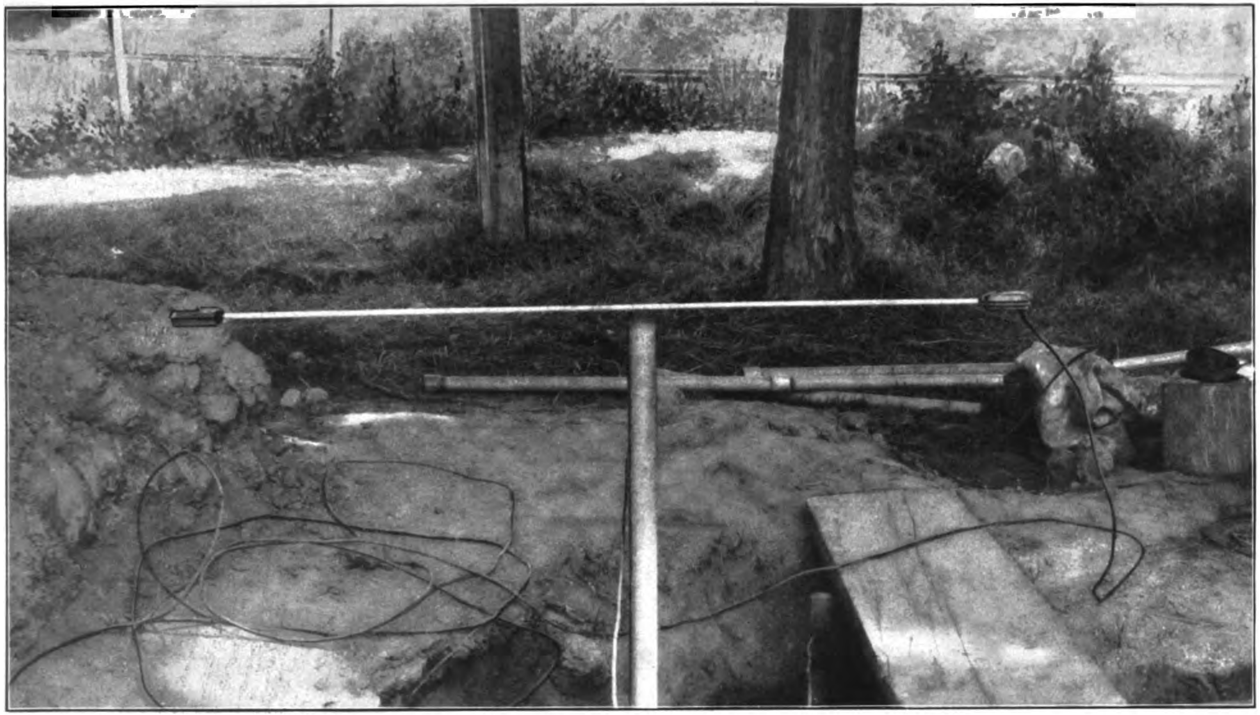
WELL POINTS.

When wells are shallow and the material to be penetrated is soil or unconsolidated sand, it is economical to drive ordinary 1¼ or 2 inch points. These are usually in 4-foot lengths and are made by perforating standard or extra-strong wrought-iron pipe with seven rows of oblong holes three-eighths by one-half inch. Around the outside of the perforated pipe is wrapped a fine brass screen of No. 35 wire with about 2,500 meshes per square inch; over the gauze is wrapped a perforated brass screen with 28 one-eighth inch holes per square inch, the whole being securely soldered to the perforated pipe along the vertical seam. The gauze strains out the fine sand and silt, but allows the water to enter the well, and the brass screen is put on to protect the gauze. Fig. 1 of Pl. I, *A*, shows such a well point with the screen and gauze partly removed. This style of point serves for both a well and for part of the testing apparatus as described on page 26.

When the material is compact, or contains cobblestones or bowlders, these well points fail, either by bending, by breaking, or by stripping off the outside screen and gauze. If the material contains stones large enough to deflect the pipe, it will bend and either break in driving or in pulling; in fact, it is almost impossible to pull a crooked pipe, as it will break at one of the couplings. When the material is compact and coarse the frictional resistance on the screen will often strip it entirely off of the pipe, leaving it as shown in figs. 1 or 3 of Pl. I, *A*. To overcome these difficulties the experiment of placing a fine screen on the inside of the perforated drive pipe was tried and found quite satisfactory. Perforated sheet brass, known to the trade as No. 26 gage, No. 1, with 400 holes, about 0.02-inch in diameter per square inch, should be rolled into a tube slightly smaller than the inside diameter of the perforated pipe (fig. 5 of Pl. I, *A*), securely soldered along the vertical seam and shoved inside the perforated pipe, where it is held in place by the couplings above and below. It is largely protected from injury and can be withdrawn and cleaned if necessary. Such a well point is shown in fig. 4 of Pl. I, *A*. The only objection to this style of point is that the holes in the outside tend to fill with sand and clay when the pipe is pulled.

JACKSCREWS.

The jackscrews for pulling pipe should be strong, of at least 32 tons capacity each. A clamp of heavy flat iron, a pulling ring, and steel wedges or dogs with notched edges should be provided for hold-



ELECTRODES AND WELL.

ing the ring in place when the pipe is being pulled. The arrangement of the jackscrews, etc., is shown on Pl. III, *B*.

PLACING WELL POINTS FOR UNDERFLOW TESTS.

As noted above, ordinary well points are driven into the pervious strata where it is proposed to test the underflow.

When the heavy drivepipe is used the procedure is somewhat different. The pipe is driven by machinery to bed rock, or to the desired depth, and thoroughly cleaned from sand, silt, etc. A length of well screen similar to that shown in fig. 4 of Pl. I, *A*, is screwed to a sufficient length of 1¼-inch standard pipe and lowered to the bottom of the hole. The drivepipe is then pulled up, leaving the well screen and 1¼-inch pipe in the ground with the screen at the proper depth. The drivepipe is used to sink another well, in which is placed another screen, etc., until all the well screens of the group are in place. The well screens and small pipe, whether set by the first or the second method, now form part of the testing apparatus, being a portion of the electric circuit.

TESTING APPARATUS.

The various instruments at first used in testing the velocity of underflow were made from designs furnished by Prof. Charles S. Slichter. The modifications of the original apparatus and the methods developed are the result of several months' experimenting by the writer, and may be of value to investigators in the future.

WIRE.

The wire should be a good quality of rubber-insulated copper, about No. 14. Single wires are more convenient than a cable or a twisted lamp cord. Care must be used and the wire examined occasionally to see that the insulation is not worn through, for if it is there will probably be a short circuit between the well casing and the wire. It should be kept rolled into open coils, and not kinked or twisted, as such usage tends to break the insulation.

ELECTRODES.

The electrodes are brass rods from one-fourth to five-sixteenths inch in diameter and about 4 feet long, usually nickel plated (Pl IV). They should be heavy, of solid metal throughout, as it is difficult to sink a light electrode to the bottom of a deep well. The wire should be attached to the electrode by some such device as that shown in fig. 8, this being necessary in deep wells. It should not be bent or kinked where attached to the electrode, as it may break and leave the electrode in the bottom of the well. The electrodes are insulated from the well casing by means of wooden blocks (see fig. 8), which should be boiled in paraffin to make them impervious to water. The electrodes will need frequent plating, as the action of the electric current and of the sal ammoniac quickly corrodes the nickel coating.

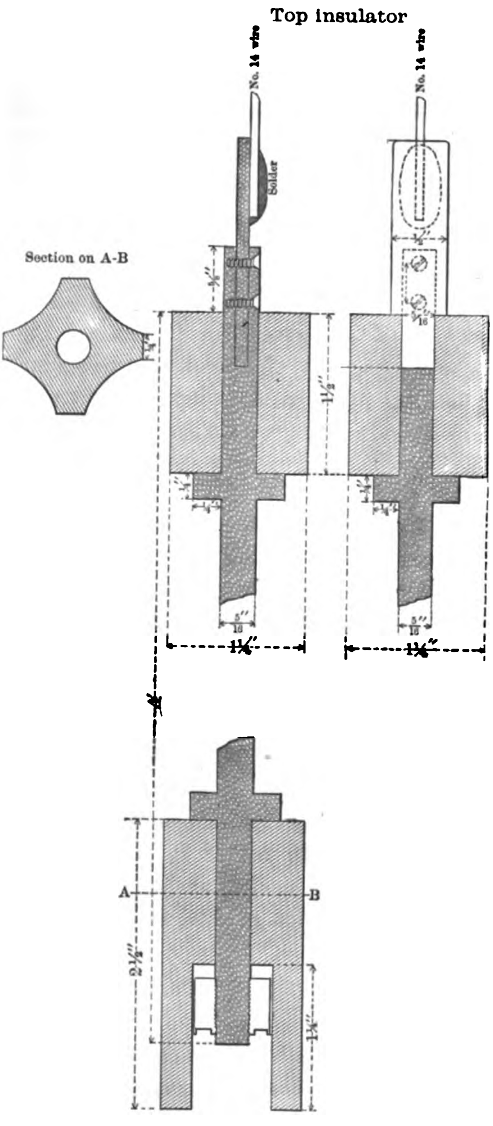
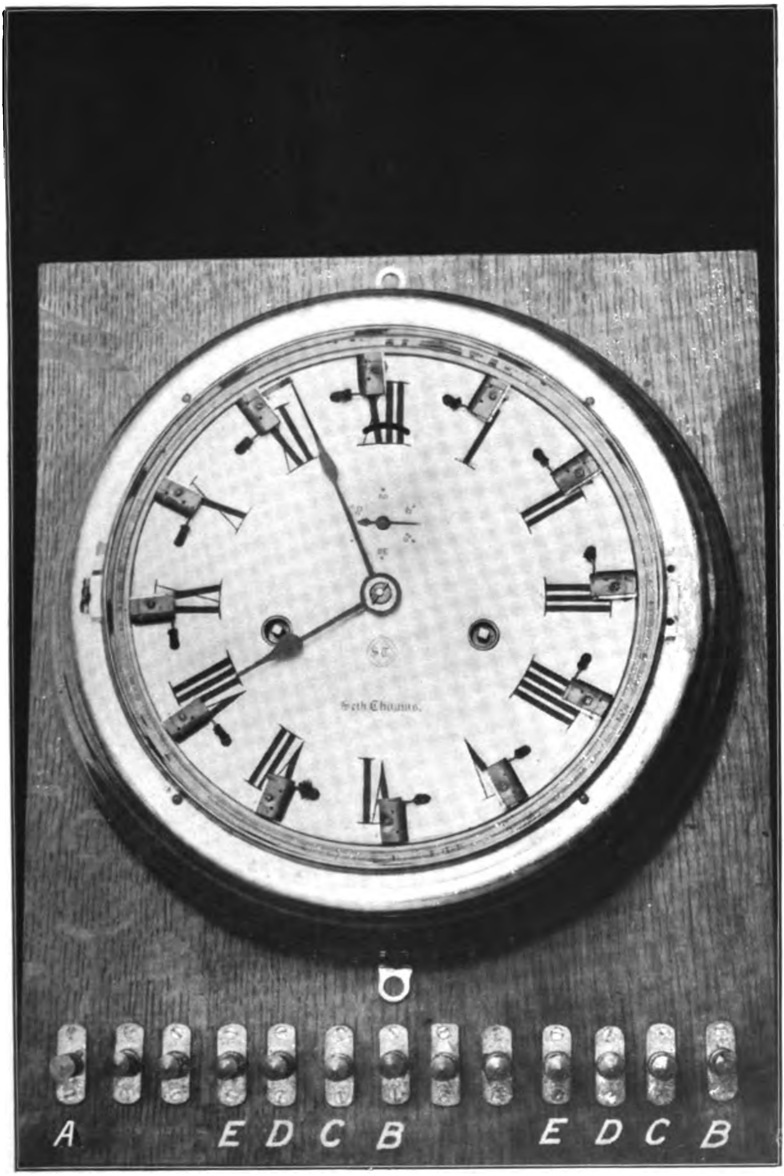


FIG. 8.—Electrodes.

SWITCH CLOCK.

A switch clock found satisfactory in actual use is shown in Pl. V. It is an ordinary eight-day clock with electrical devices added. The minute hand of the clock carries a steel spring, tipped with platinum, which, at five-minute intervals, is brought into contact with platinum strips, each of which is connected with a separate insulated wire passing down through the clock case and thence to the proper binding post. Each contact closes a circuit through one of the test wells. The platinum strips are laid in slits cut in lugs of hard rubber. The strips, the projection of which beyond the edge of the lug is adjustable, are held in place by screws which pass through narrow slots. The hard-rubber lugs are permanently fastened to the clock dial by screws from the back. They are placed at each hour on the dial or at five-minute intervals as measured by the minute hand.

In operating, the spring on the minute hand is carried over the hard-rubber lug, which is so placed that the spring is slightly raised. When the tip of the spring reaches the sharp edge of the lug it suddenly snaps down on the platinum strip and at once closes the circuit. It is



SWITCH CLOCK.

pulled across the platinum strip by the motion of the hand and when it reaches the edge snaps away from the strip, suddenly opening the circuit. The time the circuit is closed can be regulated by adjusting the width of the strip. Five to ten seconds is about the proper interval. It is important that the circuit be opened and closed suddenly, otherwise the recording pen, full of ink, may move back and forth on the chart several times and probably obliterate the record.

The current from the positive pole of the battery enters the clock at one of the binding posts, *B*, *C*, *D*, *E*, etc., and passes through the insulated wire to the minute hand, thence to the clock frame and out to the binding post marked *A*. By the movement of the minute hand the circuits to the various wells are progressively closed. The twelve switches on the dial permit of thirty hourly records with four lower wells and a thirty-minute interval between records, as shown on Pls. V, *A*, and VI, *B*, or of records at intervals of twenty minutes with three lower wells and a ten-minute interval between records. It is also evident that in the first case two groups of wells, or in the second case three groups of wells, can be tested hourly at the same time, with a ten-minute interval between tests.

RECORDING AMPERE METER.

The recording ampere meter (Pl. VII, *A*) was made by the Bristol Company from designs furnished by Prof. Charles S. Slichter. The instrument keeps a continuous record for twenty-four hours, after which the chart must be changed. The chart is moved at a uniform rate by clockwork. The recording pen is actuated by the electric current sent through the wells at fixed intervals by the switch clock. The electric apparatus is very simple, consisting of a stationary solenoid through which the current passes. A thin disk of soft iron is attached to a nonmagnetic shaft which passes through the solenoid and is supported at its opposite ends by steel knife-edge springs. The recording pen is secured directly to the steel springs and partakes of its angular motion as the disk is attracted by the solenoid. The result is a record such as shown on Pl. VI, *A* and *B*.

If an ordinary ampere meter is used the switching must be done by hand, as described on page 27.

BATTERY.

The electric battery should be of ample capacity. Dry cells known as large-size Columbia, 3½ inches in diameter and 8 inches high, have been found satisfactory. The plan and wiring of the battery for use with a recording ampere meter only are shown in fig. 9, and for use with either a recording or ordinary ampere meter are shown in fig. 10.

The battery consists of 12 large-sized dry cells connected in sets of two in parallel. These parallel sets are connected up in series, and by means of the double-throw switches the electromotive force of the battery can be varied from 1.5 to 9 volts, assuming the electromotive force of each cell to be 1½ volts when new. One, two, three, or more sets of two cells connected in parallel can be used in one series, as the case requires, or if necessary either side of the battery can be cut out by the opening of one of the single-throw switches marked "A, A′." An ordinary ampere meter should, for convenience, be placed in the battery box. Fig. 10 shows such a battery connected up to a group of four wells and arranged for use with an ordinary ampere meter. The switches are set for measuring the current from casing of well B to the electrode of well B, with two sets of cells in series.

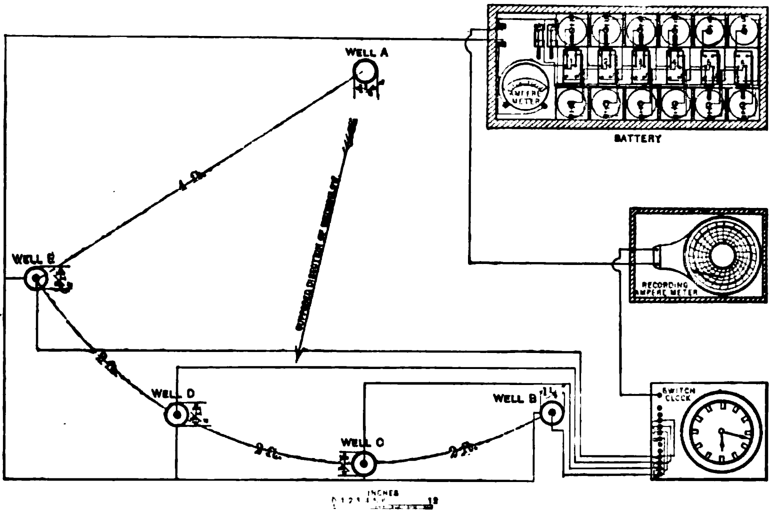


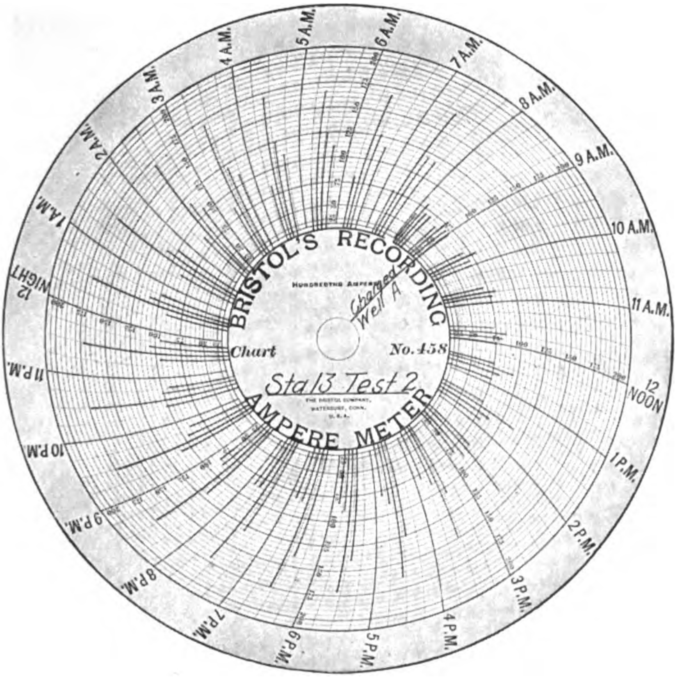
FIG. 9. Plan of test wells and apparatus.

METHOD OF MEASURING THE VELOCITY OF UNDERFLOW.

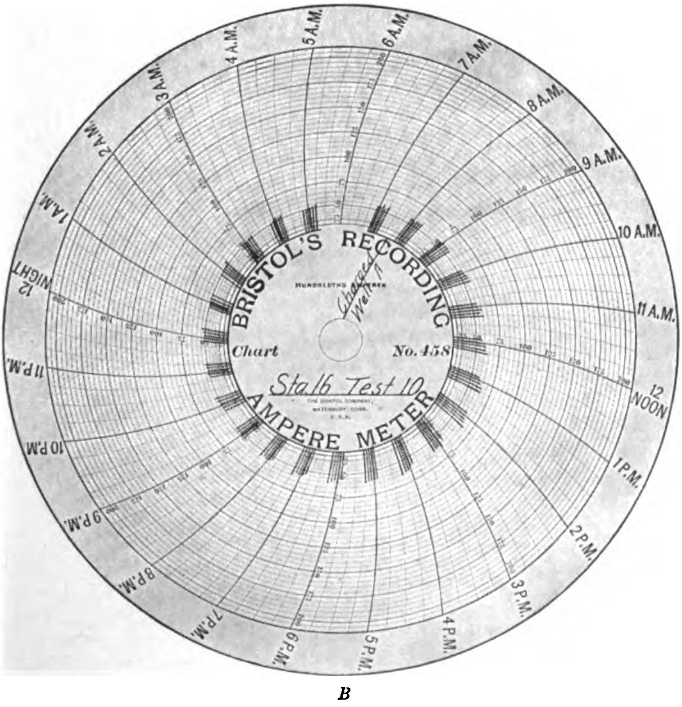
An outline of the method invented by Prof. Charles S. Slichter has been described on page 11. The following is a description more in detail of the writer's experience during several months' work at Los Angeles, Cal. An attempt has been made to describe the difficulties encountered and the methods developed during the progress of the work.

PUMPING.

After all the test wells have been sunk, as described on page 11, it is necessary before beginning a test to take a small sand pump and thoroughly clean the inside of the well points from sand and silt, and then pump water from each well until it clears. A small hand pump which can be readily moved from well to well is convenient for this



A



B

CHARTS USED WITH RECORDING AMPERE METER.

purpose. Pumping is often a tedious job, as the screens become clogged with silt and mud. In such cases a few buckets of clear water poured down the well will often open up the screen. Another way is to occasionally break the vacuum in the pump and let the water in the pipe fall back suddenly. When these methods fail, success may be attained by rotating the pipe with a pair of tongs and at the same time pouring clear water down the well.

If some of the wells pump freely and the rest will not start, it is almost certain that the screens are clogged, and if all else fails they may be allowed to stand a day or two. If none of the wells can be started, or after starting continue to pump fine sand and mud, the test may as well be abandoned, for in such cases the velocity will be too low to measure by this method. Testing should not be begun for a few hours after pumping, in order to allow the water plane to rise to its normal level.

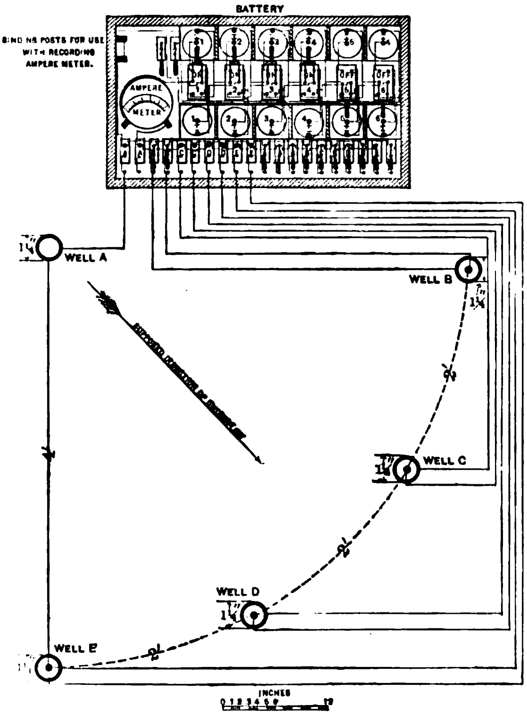


FIG. 10. Plan of test wells and apparatus.

WIRING.

The next step is to wire the wells. There are several ways in which this may be done, depending on the kind of electrical instruments used. If a recording ampere meter is used, the wiring should be as shown in fig. 9. A wire is run from the positive pole of the battery to the casings of lower wells B, C, D, E, etc., all of which may be connected by soldering the wire to the galvanized casing of each, thus insuring good connections. A wire is connected to the electrode for each well and run to the proper binding post on the switch clock; the electrodes should then be lowered to the bottoms. From the positive binding post of the switch clock a wire is run to the recording ampere meter, and from the ampere meter to the negative pole of the battery. An ordinary ampere meter (in the battery box) is put in the circuit to check the record of the recording instrument.

The current recorded is that which passes through the water between the casing of the wells and the electrode at the bottom of the well.

The construction of the clock, recording ampère meter, battery, etc., is described on pages 21 to 24.

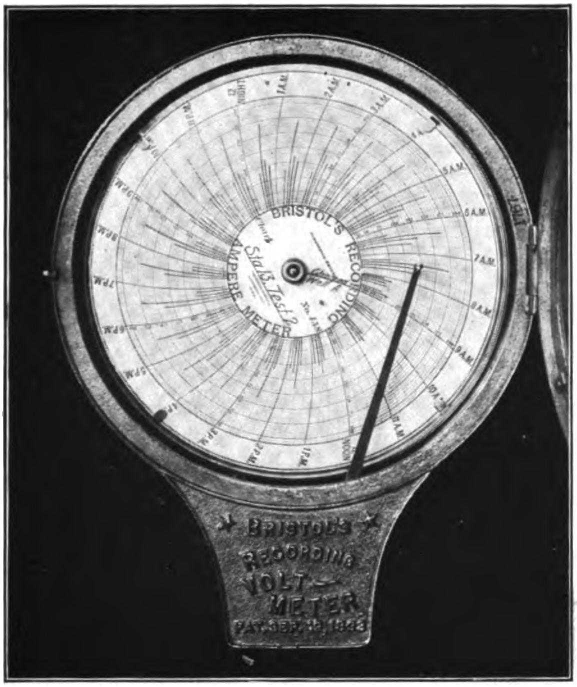
If an ordinary ampere meter is used the wiring will be quite different, as all switching must be done by hand. A battery arranged for such a testing and the wiring of a group of wells is shown in fig. 10. A wire should be run from the proper binding posts, marked A, B, C, D, and E, of the battery to the casing of the corresponding wells, and another from the binding posts, marked B′, C′, D′, E′, of the battery to the electrodes of the corresponding wells. The battery is so wired that when the switches A and B are closed, the ampere meter indicates the amount of current flowing through the ground from the casing of well B to the casing of well A. When the switches B and B′ (fig. 10) are closed, the ampere meter indicates the amount of current flowing through the water from the casing of well B to the electrode of well B. After all the wiring is done, the correctness of the various connections should be tested. If the circuit through one of the wells is closed and the electrode lifted out of the well, the amperemeter needle should fall back to zero, for raising the electrode out of the well opens the circuit. On the other hand, if the casing of the well is touched with the electrode, a strong deflection of the needle should be noted. By these tests an error in wiring may be detected.

CHARGING WELL A.

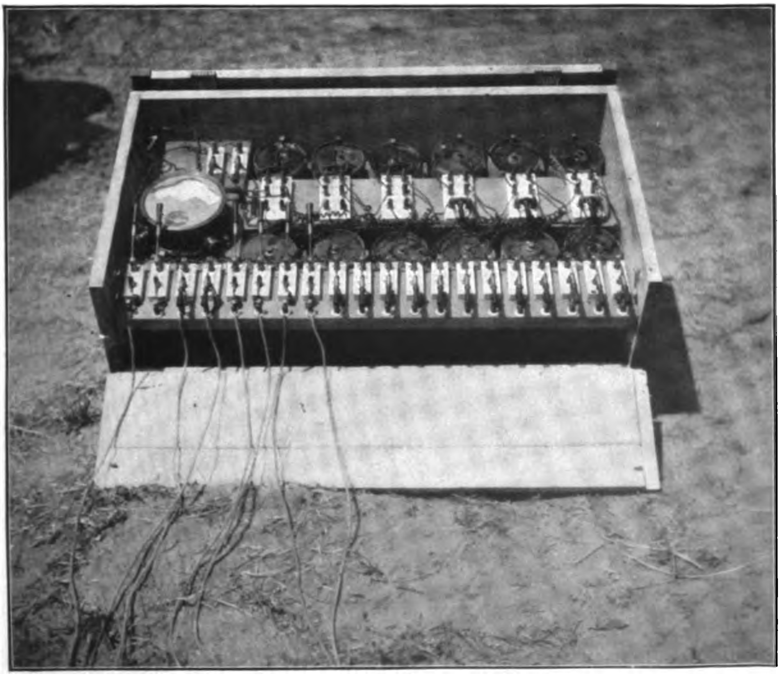
After all the connections have been made and tested, a new chart should be placed in the recording ampere meter, and the apparatus allowed to run for an hour or so, to get a record of the wells before well A is charged.

Various methods of charging wells have been tried, and the following has finally been adopted. The electrolyte used is sal ammoniac (NH_4Cl). This should be placed in a small wooden or paper tub (it rusts iron quickly) and enough water poured on to cover it. A bucket of perforated sheet brass, similar to that used for the inside screen of the well points, about 4 feet long and small enough to readily slip down the inside of the well pipes, should be provided. This should be placed in the tub of wet sal ammoniac and filled with water and the salt by means of a funnel and dipper. The water will drain away into the tub and leave the wet sal ammonia filling the bucket, which should at once be lowered to the bottom of the well.

It is difficult to get a bucket of dry sal ammoniac down a deep well on account of the contained air. In addition, the escaping air causes the formation on the water of a sticky foam, which is carried down by


BRISTOL'S RECORDING AMPERE METER
BRISTOL'S RECORDING VOLT METER

A. RECORDING AMPERE METER.



B. BATTERY.

the next bucket and clogs the screen. The experiment of pouring a hot saturated solution of sal ammoniac down the well pipe was tried, but was condemned. It will either crystallize out when the water cools and leave the pipe filled solidly with the salt, or, if the strata be pervious, will be forced through to the lower wells almost immediately. In any case, undissolved sal ammoniac should not be poured down a well, as it is almost impossible to clean it out for the next test.

The following rule is now observed in charging wells: Put down one bucket of wet sal ammoniac every fifteen minutes for two hours, then one bucket an hour for six hours. Of course, if at any time the electrical instruments show that the sal ammoniac has reached the lower wells, charging should be stopped at once.

DETERMINATION OF VELOCITY OF UNDERFLOW.

When recording instruments are used, it is only necessary to examine them occasionally to ascertain when the sal ammoniac reaches the lower wells. Its arrival is indicated by an increased deflection of the recording pen, as shown by the chart in Pl. VI, *A*. When the velocity is great the deflection is sudden, but when it is low the increase is not so marked. When there is no underflow the deflection of the pen remains the same throughout the test, as shown in Pl. VI, *B*.

When an ordinary ampere meter is used, the circuits to the various wells must be closed by hand at frequent intervals, varying from ten minutes to two hours, depending on the velocity of underflow. When it is probable that the velocity is great, readings must be made often; but if no flow is detected for two or three hours, the time between observations may be longer. The ampere meter must be read and the time and readings recorded in a notebook. From the notes an ampere curve should be platted (fig. 11), from which an estimate of the velocity of flow can be made. The sudden rise in the curve indicates the arrival of the sal ammoniac at the lower well. This rise is primarily due to the fact that the solution of water and sal ammoniac is a better conductor of electricity than is water alone, and when this solution flows into and mingles with the pure water in the well, the rise in the current, due to lessened resistance, can at once be noted.

The time of passage of the solution from well A to one of the lower wells is usually calculated from the hour when charging was begun to the hour when the rising ampere curve reverses, or, in other words, at the point of the maximum rate of increase in the ampere curve. This method corrects for the diffusion or spread of the sal ammoniac in the water and for the error due to the fact that the water in the upper well can not be charged quickly.

The distance between the wells being known and the time of passage of the solution having been noted, it is a simple matter to compute the velocity or rate of flow. This may be expressed in any unit of measure desired. In this report the rate of flow is expressed in feet per day.

When wells have been sunk with the heavy drivepipe, as described on page 21, and the well screens inserted, the first test will evidently be at bed rock, or at the bottom of the hole. After the completion of the first test, the pipe may be pulled up the length of the screens and another test made. This pulling up and testing may be continued to the level of the water table if desirable.

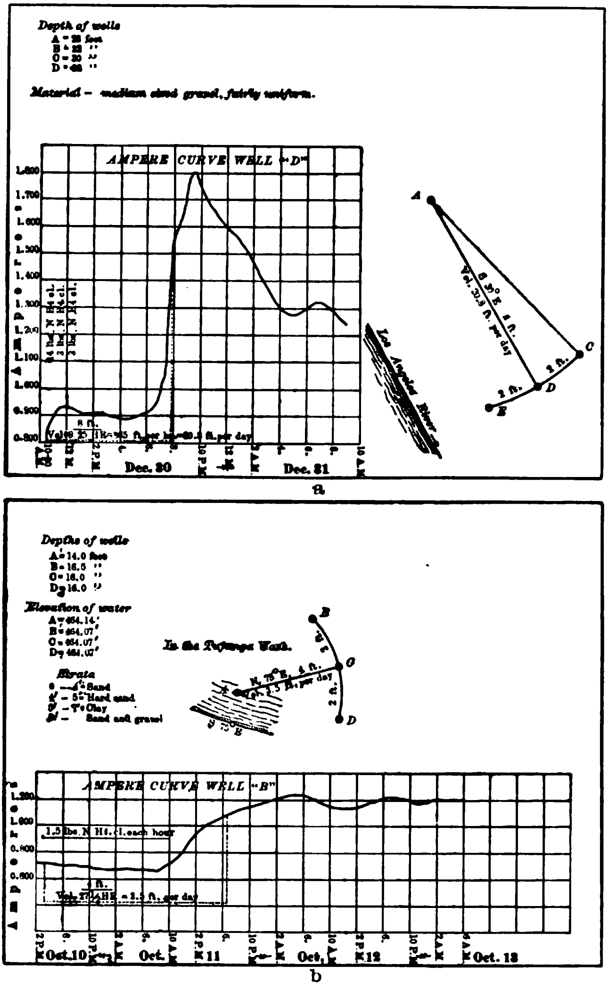


FIG. 11.—Ampere curves.

When well points are driven by hand, it is best to drive into the first stratum below the water table, test it, and then drive deeper, continuing the process as far as necessary.

COMPUTATIONS OF DISCHARGE.

In a given section wide differences in the velocity of underflow are to be expected, due to the various factors on which flow depends, such as slope of the water table, porosity, relative size of the sand grains, temperature, etc. It is evident that if the actual percentage of the open spaces or voids between the particles of sand and gravel of each square foot of a measured section was known, and the average velocity at which water flows through the ground had been measured, it would be possible to compute the amount of water passing a given line during a fixed interval of time; moreover, no further data would be necessary.

The difficulties met with when an attempt is made to compute the discharge from a section should be clearly set forth.

Natural sands, as dug from pits or the bed of a stream, consist of grains of different sizes and shapes. Such sand weighs more per unit of volume, as per cubic foot, than any of the various grades of sand sifted from the same bed and having grains of nearly uniform size. This proves that the natural sands contain a less percentage of voids, or, in other words, the porosity is less, than that of the sorted sands.

Experiments made by Prof. F. H. King[a] show that the porosity of unsorted sands from the Tujunga washes in San Fernando Valley, Los Angeles County (see fig. 12), varies from 31.42 to 42.28 per cent. The effective diameter of the sand grains was ascertained to range between 0.05542 and 0.4289 millimeters. The same writer says:

> It appears to be generally true that well-rounded grains of nearly uniform diameter tend to give a pore space which lies between 32 and 40 per cent. The mean theoretical pore space for spherical grains of a single size is 36.795 per cent, and this is very close to the mean observed limit for the more simple sands of rounded grains.

A sample of coarse sand from Arkansas River Valley was tested by G. W. Stose in the following manner:

> After being thoroughly dried it was saturated with water, and the quantity of water received was determined by weighing. The vessel containing it was then punctured at the bottom, so as to permit the water to drain away, and after a lapse of several days the loss of water was determined by another weighing. It was then found that the sand had received 29 per cent of its volume of water, but afterwards parted with only one-third of the water received, equivalent to 10 per cent of the whole volume of sand.[b]

Both of these samples had been removed from the original beds. The experiments show the probable range of porosity in clean sand of moderately uniform size.

Prof. Charles S. Slichter states that "the porosity of quartz sand will usually vary between 30 and 40 per cent, and that of clay loams between 40 and 50 per cent, depending upon the variety of sizes in the mixture and the manner of packing the particles."[a]

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[a] King, F. H., Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1899, p. 212.

[b] Gilbert, G. K., Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 600.

Very little is known regarding the porosity of naturally deposited and undisturbed beds composed of coarse gravels, coarse and fine sand, and silt. Theory indicates that such beds, having been deposited by the action of running water, or by the waves and currents of the ocean, are far less porous than sands of uniform size, the sorting action of the water tending to pack the material as closely as possible.

It is usual to assume that the porosity of sand is about 33 per cent, and if the grains are rounded, of nearly uniform size, and free from silt, the assumption is, without doubt, about correct.

The actual porosity in each case must be known before any reliable computation of discharge can be made. Concerning this factor, Professor Slichter says:

> If two samples of the same sand are packed, one sample so that its porosity is 26 per cent and the other sample so that its porosity is 47 per cent, the flow through the latter sample will be more than seven times the flow through the former sample. If the two samples of the same sand had been packed so that their porosities had been 30 and 40 per cent, respectively, the flow through the latter sample would have been 2.6 times the flow through the former sample. These facts should make clear the enormous influence of porosity on flow, and the inadequacy of a formula of flow which does not take it into account.[b]

Evidently beds which consist of a mixture of bowlders, cobblestones, fine sand, and silt will have a less percentage of voids than graded sand. No flow can occur through bowlders or cobblestones, and if they make up 50 per cent of the volume, and the intervening spaces are filled with sand and silt of graded sizes, there is certainly far less than 33 per cent of voids in the mass. How much less must be determined by experiment.

It is exceedingly difficult in underflow tests to come to any satisfactory conclusion regarding the porosity of the various beds. This is due to the almost insurmountable difficulties in collecting representative samples of the material penetrated. If the testing is done with a small-size drive pipe, 2 to 4 inches, all the coarse material must be excluded, because it is impossible to get it into the pipe or to the surface. When the material is very coarse, it is obviously necessary to dig a well or shaft, or put down a large bore well, 12 inches or more in diameter. Both methods have decided limitations.

It is impracticable, by any reasonable expenditure of money, to dig a well much below the level of the water table. If a large-bore well is sunk, material below the water table must be brought to the surface in a sand bucket. The continual churning of the sand bucket under water washes the fine silt and mud out of the sand and mixes it with the water in the well. This mixture of mud and water is partly bailed out with each bucket partly filled with sand. How much silt is washed out by the water at any particular point is, of course, impossible to say, but if one will catch the muddy water from the sand bucket and let it settle he will be convinced that it is usually no small amount. No one can tell exactly at what depth or how much of the sand contains silt. It is entirely possible that a bed of clay or silt a foot or more thick may be entirely mixed with the water in the well and no evidence of its presence be shown unless the driller notes that the water is more muddy than usual.

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[a] Slichter, Charles S., The motions of ground water: Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, p. 17.

[b] Slichter, Charles S., Nineteenth Annual Report U. S. Geol. Survey, pt. 2, 1899, p. 323.

The writer has seen samples of sand taken from wells, carefully washed, cleaned from all silt, clay, etc., and then bottled up and exhibited as water sand. Any estimate of discharge based on such samples is utterly misleading.

Samples are often collected by catching the sand, etc., brought up by a hydraulic rig. Of course these samples are thoroughly washed. In porous gravel the wash water used in hydraulicking continually tends to flow away from the well, being under great pressure. That it carries the fine material near the hole away with it is proved by the fact that the sinking of the wash water when drilling in gravel can often be prevented by pouring clay down the well, which soon fills the voids in the surrounding gravel.

The hydraulic and drive-pipe method of sinking test wells has one great advantage over the sand bucket, in that the presence of a bed of clay or silt is shown at once by the muddy water which rises to the surface through the drive pipe. The depth at which such beds occur can by this means be ascertained.

Another uncertain factor is the unknown horizontal extent of the pervious beds. It can only be assumed that they extend from station to station, and in regions where the pervious beds have been deposited by torrential streams this assumption may lead to error, such gravel beds often being in the form of long trains of coarse material, the buried channel of the stream, and not in a wide extended sheet as supposed by many. To correct for this uncertainty, it is obviously necessary to sink test wells at close intervals along the cross section.

There is much uncertainty regarding the weight to be given velocity measurements. As a rule the velocities recorded are the maximums. Suppose test wells are set 4 feet in a pervious stratum, the upper two feet of which is composed of coarse sand 2 millimeters in diameter, the lower two feet composed of fine sand 0.4 millimeter in diameter, with a pressure gradient of 10 feet per mile. As computed from tables prepared by Prof. Charles S. Slichter,[a] the velocity of flow in the upper bed will be at the rate of 5,386 feet per year, and in the lower bed at the rate of 216 feet per year. In the first instance this is at the rate of 14.75 feet per day, and in the second at the rate of 0.59+ foot per day.

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[a] Slichter, Charles S., The motion of underground water: Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, p. 29.

If the test wells are spaced 4 feet apart the chemicals used in charging the upper wells should pass through the coarse stratum and reach the lower well in about six and one-half hours, while it will take about one hundred and sixty-two and five-tenths hours for the same chemical charge to reach the lower well through the fine stratum. In such a case, the salt passing from the upper bed would enter the lower well and cause a sudden rise in the current, as recorded by the instruments. The sal ammoniac in solution, being much heavier than the ground water alone, will settle and fill the lower well. There is no doubt but that the result is correct for the upper 2 feet, but, as the lower well is full of the solution of sal ammoniac, there will be no means of ascertaining when the charge from the lower stratum reached the well, even if the test should be continued for six and three-fourths days, which is highly improbable. It is in fact impossible to know, in testing material naturally deposited, whether the flow is through the whole section tested or through one or two thin strata. The only practical method is to use short well points and test the ground at each few feet in depth.

The most promising field for this method of testing underflow is in regions where the pervious formations are uniform in composition and texture throughout wide areas, and where the water table is not subject to great fluctuations in level. If testing in mountainous regions or in the débris cones of torrential streams is attempted, the testing stations should be close together and tests made at many points and at various depths, to eliminate as much as possible the inaccuracies due to varying texture and porosity of the formations.

BASIN OF LOS ANGELES RIVER.

The drainage basin of Los Angeles River has an area of approximately 502.5 square miles.

The principal eastern tributaries of this stream rise on the west slopes of San Gabriel Mountains and flow down to San Fernando Valley in deep rocky canyons which have been eroded in the granitic rocks of the range (see fig. 12). These streams are torrents during the rainy season, but dwindle to mere rivulets in the summer. When in flood they transport a vast amount of detritus, sand, gravel, and bowlders to the plain below, and have buried the old drainage lines across the east end of San Fernando Valley beneath extensive detritus cones, into which the surface streams sink except in times of extraordinary floods.

The western tributaries of Los Angeles River rise in Santa Susanna Mountains, which bound San Fernando Valley on the north, and in

Santa Monica Mountains on the south. These streams are small, rarely reaching the eastern end of the valley. They flow over sandstones, shales, clays, etc., and are strongly impregnated with alkaline salts, in strong contrast to the pure water from the granitic range to the east.

After flowing southerly in a broad underground channel beneath the detritus in the east end of San Fernando Valley, the water of Los Angeles River is deflected easterly by the impervious rocks of Santa Monica Mountains. This barrier, taken together with the contraction of the underground channel, so obstructs the free percolation below that much of the ground water rises and flows as a surface stream again.

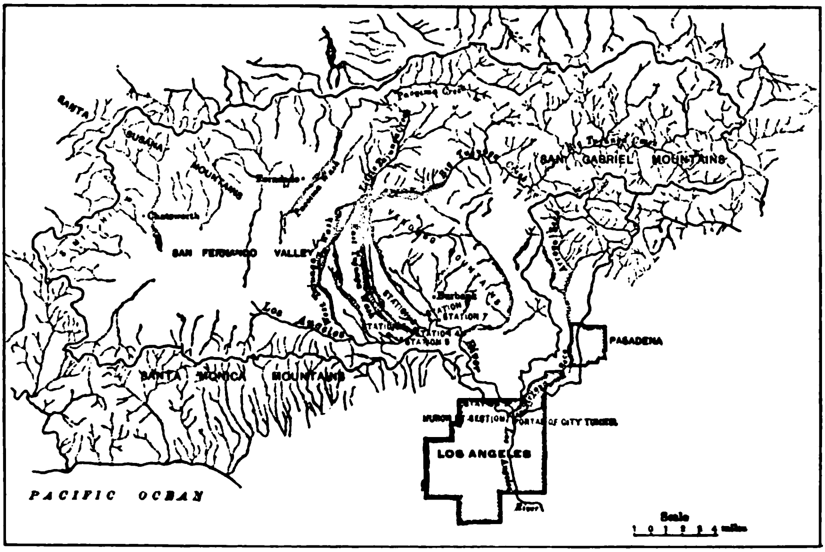


FIG. 12.—Drainage basin of Los Angeles River.

After rounding the eastern end of Santa Monica Mountains the river flows through a region of low, rolling hills in a valley which is about 2½ miles across at the widest place and narrows to half a mile at Los Angeles, 6 miles below. This valley was formerly deeper than at present, and, in common with San Fernando Valley above, has been partially filled with river detritus, which near the mountains is very coarse but becomes fine and contains beds of sand and silt toward the south. The gradual change from coarse to fine material in connection with the contraction of the underground channel without doubt causes the rise of ground water along this 6-mile section of the river. At the mouth of the Arroyo Seco a marked change occurs in the character of the stream detritus. This stream is steep-graded and torrential, heading on the precipitous slopes of San Gabriel Mountains (see fig. 12). After leaving the mountains it flows in a canyon cut across the hill country to its junction with Los Angeles River. It carries bowlders, coarse gravels, and sand into the river valley, and its wide-spreading débris cone at the mouth of the canyon has forced Los Angeles River to the southwest side of the old valley. There is evidence that this débris cone was once more extensive than now, and it without doubt then acted as a barrier to the flow of the river, thus perhaps accounting in a measure for the fine material in the valley immediately above. About 2 miles below Huron street the river flows out on an alluvial plain and the surface stream soon sinks.

Lower Los Angeles River, extending from Huron street 12 miles northwesterly, being supplied by underground water, is remarkably uniform in its discharge, little difference being noted throughout the year. The entire surface and part of the underflow is diverted by the city of Los Angeles for domestic use and irrigation.

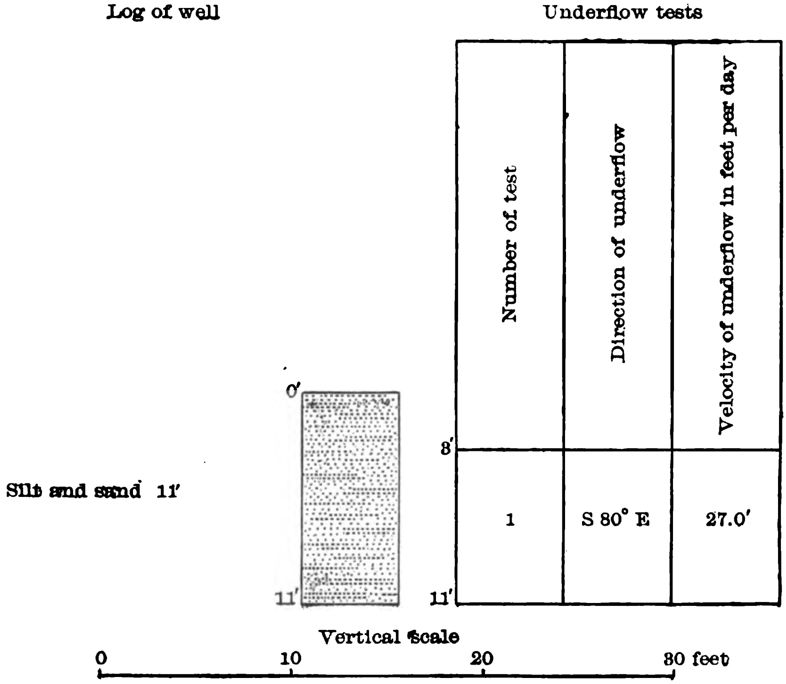


FIG. 13.—Underflow tests at station 1.

TESTS IN 1902.

The following preliminary tests were made in Los Angeles River valley during September and October, 1902. The tests made at stations 1 and 2 were mainly for the purpose of adapting the apparatus to local conditions.

STATIONS AND RESULTS.

Station 1 is in Los Angeles River bed, at the Los Felis road bridge, near Huron street (see fig. 21). A group of well points was driven by hand to a depth of 11 feet. The velocity of the underflow was 27 feet per day between 3 feet and 11 feet, and the movement was S. 80° E., or away from the surface stream, which was actually losing water at this point. Later the water table was found to slope in the direction indicated by the underflow. The order of the strata, record of the wells, and the velocity measurements at this station are shown in fig. 13. Sixty-five feet to the east of this station another group of well points was driven to a depth of 11 feet and tested between 3 feet and 11 feet, but no underflow was detected. They were then driven to a depth of 19 feet, and tested between 11 feet and 19 feet, with the same result. As these were driven wells no samples were collected, but the material appeared to be fine silt except near the surface, where it was somewhat sandy, and it is probable that the underflow at station 1 was through this top stratum.

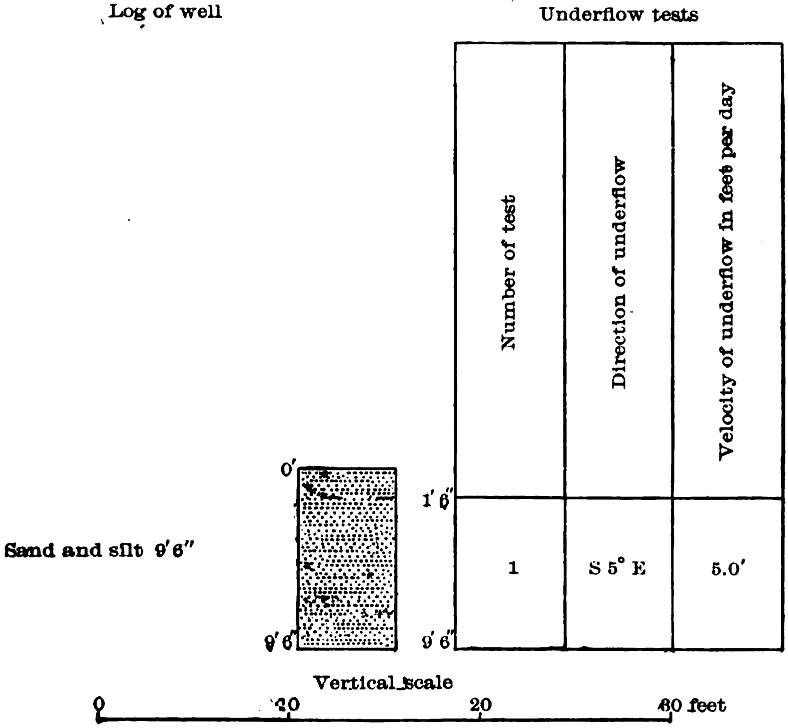
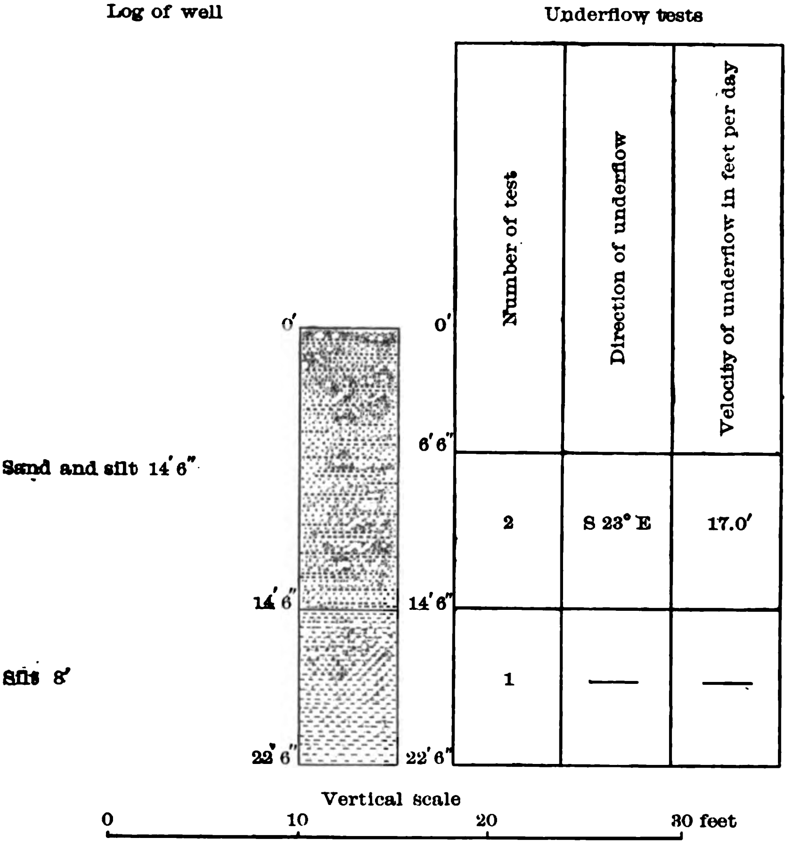


FIG. 14.—Underflow tests at station 2.

In August and September, 1903, the Southern Pacific Railroad Company dug pits for bridge piers in the river bed about 100 feet east of this point. The material penetrated was mainly mud and silt, with a few irregular seams of sand. Only the sand beds were water bearing; they are from 2 to 4 inches thick.

Station 2 is on the west side of the river, 1 mile above the Huron street section, as shown in fig. 12. A group of well points was driven by hand to a depth of 9½ feet, and a test made between 1½ feet and 9½ feet, showing the direction of the underflow to be S. 5° E., velocity 5 feet per day. No samples of the strata pierced were collected, but the amount of water pumped indicated that the ground was not porous. The order of the strata, record of the wells, and the velocity measurements are shown in fig. 14.

The testing apparatus was then moved upstream to San Fernando Valley, where the conditions of underflow and the extent of the ground water have been thoroughly studied. The object of these tests was to determine, if possible, the relation of the slope of the water table to the direction and velocity of the underflow.



Number of test	Direction of underflow	Velocity of underflow in feet per day
2	S 23° E	17.0′
1	—	—

FIG. 15.—Underflow tests at station 3.

Station 3 is on the east bank of Tujunga Wash, near its junction with Los Angeles River, as shown in fig. 12. A group of well points was driven by hand to a depth of 14½ feet, and a test made between 6½ feet and 14½ feet, where the direction of the underflow was S. 23° E., velocity 17 feet per day. The wells were then driven deeper and a test made between 14½ feet and 22½ feet, but no underflow could be detected. No samples were collected. The underflow appeared to be along the gravel beds in the bottom of the wash.

The order of the strata, record of the wells, and the velocity measurements are shown in fig. 15.

Station 4 is on the east bank of Tujunga Wash, as shown in fig. 12. A group of well points was here driven by hand, and a test made between 6½ feet and 14½ feet, where the direction of the underflow was S. 13° E., velocity 4½ feet per day. These wells were driven deeper, and a test was made as at station 3, but no underflow could be detected. The order of the strata, record of the wells, and the velocity measurements are shown in fig. 16.

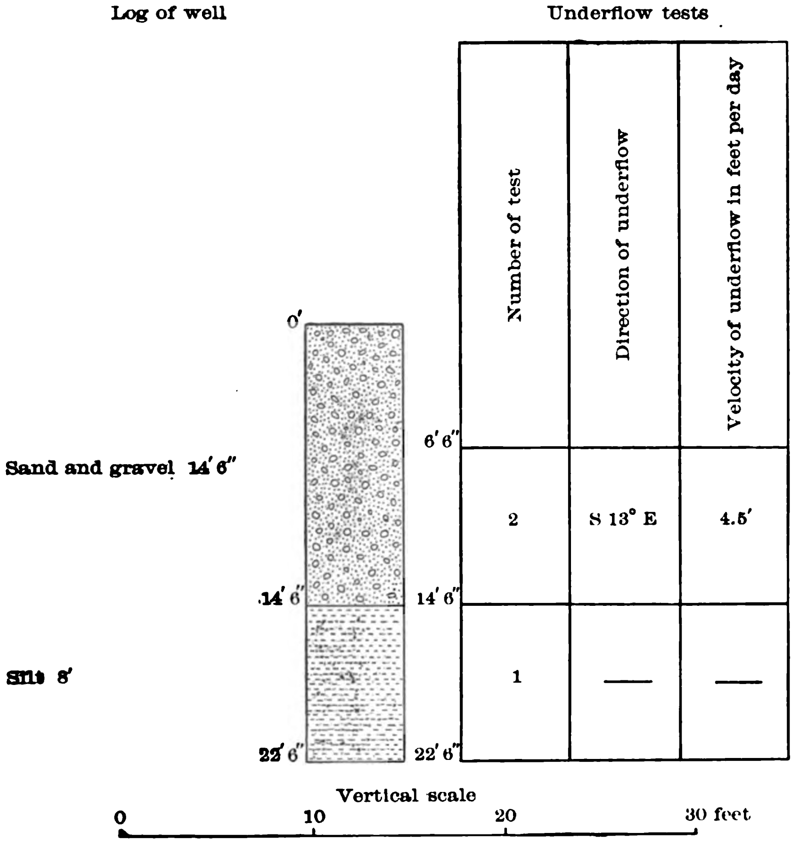


Fig. 16.—Underflow tests at station 4.

Station 5 is on Los Angeles River, near the road from Burbank to Cahuenga Pass, as shown in fig. 12. A group of well points was here driven by hand to a depth of 34½ feet, and a test made between 26½ feet and 34½ feet, where the direction of the underflow was S. 40° E., velocity 48 feet per day. The water from this depth rose to a point 6 feet above the surface, and it is possible that the high velocity was caused by leakage upward around the casing, which drew the charged water toward the well. Borings were made with a 2-inch auger at this station. The order of the strata, record of the wells, and the velocity measurements are shown in fig. 17.

Station 6 is in Tujunga Wash, south of the road from Burbank to Cahuenga Pass, as shown in fig. 12. This group of wells was driven to a depth of 16 feet, and a test made between 8 feet and 16 feet, where the underflow was N. 75° E., velocity 3½ feet per day. Borings were made with a 2-inch auger at this station. The order of the strata, record of the wells, and the velocity measurements are shown in fig. 18.

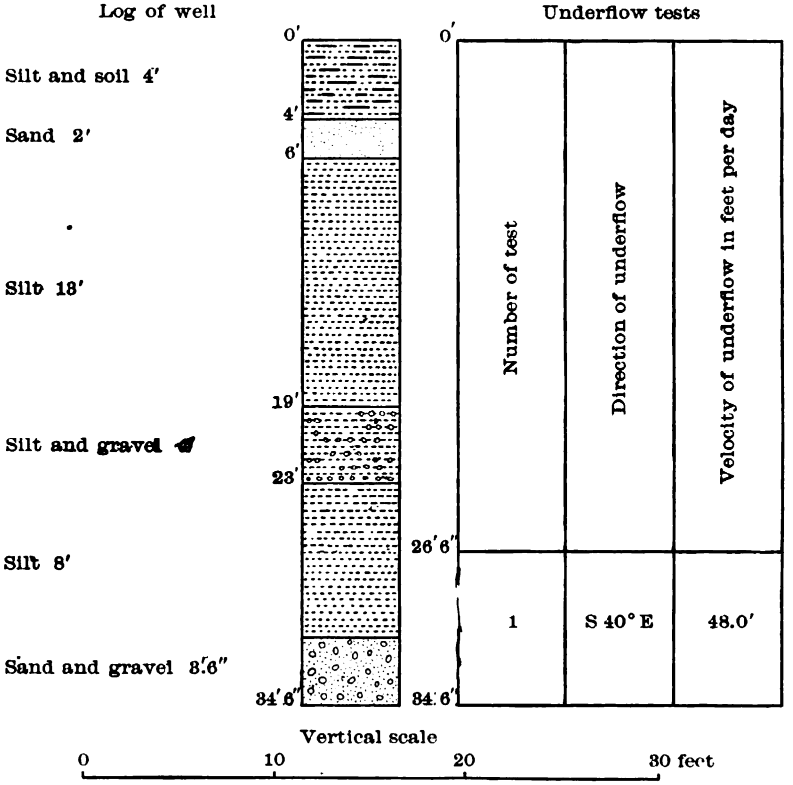


FIG. 17.—Underflow tests at station 5.

Station 7 is on the left bank of Los Angeles River, 1 mile south of Burbank, at the mouth of a broad sandy wash (see fig. 12). This group of wells was driven by hand to a depth of 8 feet, and a test made between 5 feet and 8 feet, where the direction of the underflow was due east, velocity 2½ feet per day. The underflow was away from the surface stream, and the slope of the water table was afterwards found by leveling to be in the direction indicated by the underflow. The order of the strata, record of the wells, and the velocity measurements are shown in fig. 19.

Station 8 is on the left bank of Los Angeles River, 1 mile south of Burbank, at the mouth of a sandy wash (see fig. 12). This group of wells was driven by hand to a depth of 9 feet, and a test made between 1 foot and 9 feet, where the underflow was found to be N. 60° E., velocity 6.4 feet der day. The order of the strata, record of the wells, and the direction of the underflow are shown in fig. 20.

These tests indicate that in general the underflow is in the direction of the greatest slope of the water table, although there are marked variations. No relation could be traced between the slope of the water table and the velocity of the underflow. The conclusion drawn from the few tests made was that the underflow tends to follow the most pervious strata, even if the extension of these beds varies considerably from the general slope of the water table. The maximum velocities are also found in such strata.

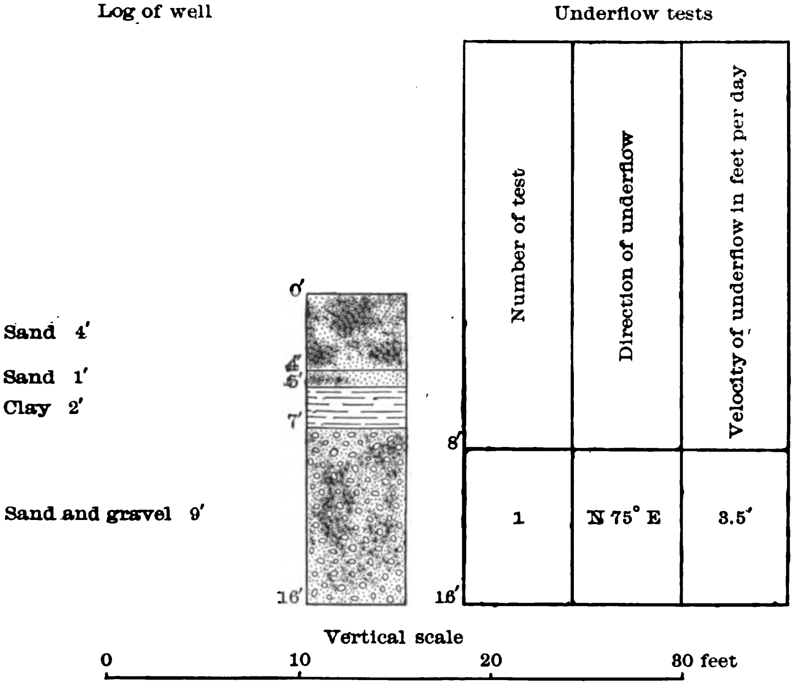


FIG. 18.—Underflow tests at station 6.

TESTS AT HURON STREET IN 1903.

Extensive tests were made at the narrows of the Los Angeles River along Huron street, Los Angeles, Cal., in 1903 (see fig. 21). This locality will be spoken of as the Huron street section. It was selected for the following reasons:

(1) In 1896 the city drilled several test wells to bed rock, furnishing valuable data regarding the cross section of the pervious gravel beds.

(2) The city water commissioners are now driving a tunnel in bed rock beneath the river channel, beginning about half a mile south of Huron street, to extend entirely across the valley (see fig. 12). It is the intention in the future to drill wells through the pervious gravels and the bed rock above the tunnel and by perforating them draw off the percolating ground water through the tunnel and pump it to the city reservoirs. It was believed that the amount of water intercepted by the tunnel would give an approximate check on the accuracy of the ground-water measurements.

(3) The locality is near shops at which tools and machinery could be repaired, or manufactured if necessary.

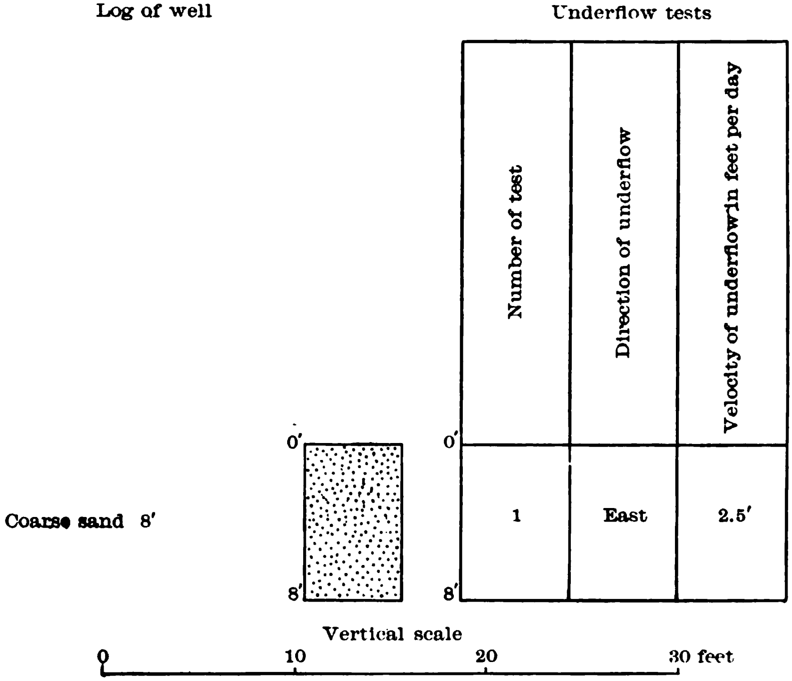
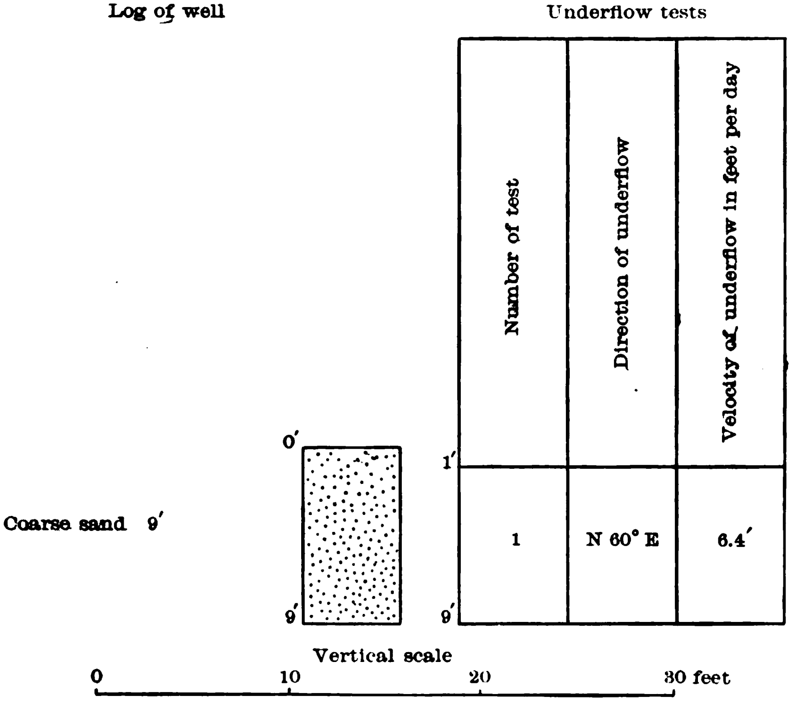


FIG. 19.—Underflow tests at station 7.

The surface profile of Huron street and the cross section of the pervious gravels below are shown in fig. 22. The points marked station 1 and stations 9 to 16 on both map and profile, figs. 21 and 22, represent groups of test wells sunk by the United States Geological Survey. The points numbered 1–7 represent test wells sunk by the city of Los Angeles in 1896, and the wells numbered 8–22 represent house wells in the vicinity. The underground cross section was platted from the information supplied by the various test wells and house wells in the vicinity. This representation of the underground conditions is necessarily incomplete, but no additional information is obtainable at present.

Attention is called to the fact that the pervious beds of sand and gravel in this section (fig. 22) fall into two distinct groups, the lower and most westerly filling the bottom of the old channel of Los Angeles River. The easterly group is without doubt the thinning edge of the Arroyo Seco débris cone. This is proved by the fact that the coarse débris from the Arroyo Seco can be traced directly to this place. The terrace at the east end of the section is also composed of the same material.

The tests of underflow point to the conclusion outlined above; in the lower gravel bed the direction of the underflow is down the general trend of the river valley, as shown by the arrows on the map at stations 1 and 9–11; while at stations 12, 13, 14, 15, and 16 the divergence from the trend of the valley is very marked—in fact, at station 15 the flow at present is up Los Angeles River Valley.



Number of test	Direction of underflow	Velocity of underflow in feet per day
1	N 60° E	6.4′

FIG. 20.—Underflow tests at station 8.

It is probable, however, that this reversion of the flow is due to the rise of the water table in the Arroyo Seco débris cone. Normally the underflow is probably from Los Angeles River down the slope of the water table, as indicated by the broken contours in fig. 21, which show the slope of the water table in December, 1902, while the dotted contours show the slope in June, 1903, the change being due, as above noted, to the floods of the Arroyo Seco. The portions of the cross section where measurable velocities were observed are diagonally cross hatched. The rest of the section appears to be practically impervious.

The depths at which the various tests were made and the direction and velocity of the underflow measured are shown in figs. 23–30.

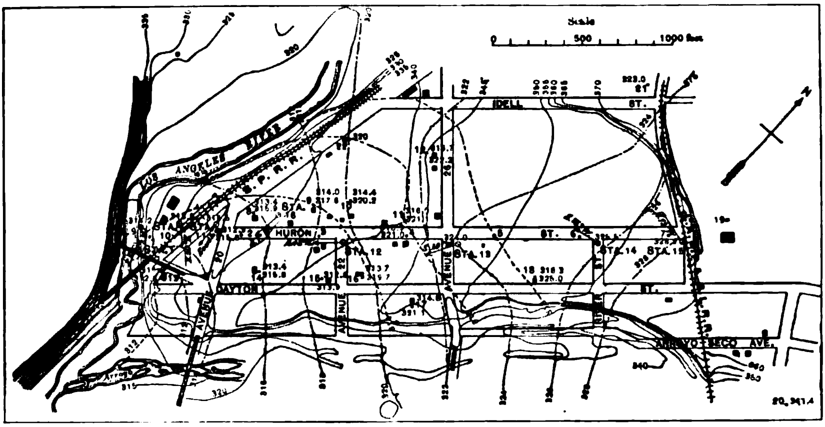


FIG. 21.—Map of Huron street and vicinity. Unbroken lines are surface contours showing topography; broken lines show form of water table in December, 1902; dotted lines show form of water table in June, 1903.

Attention is called to the general agreement in the slope of the water table and direction of the underflow.

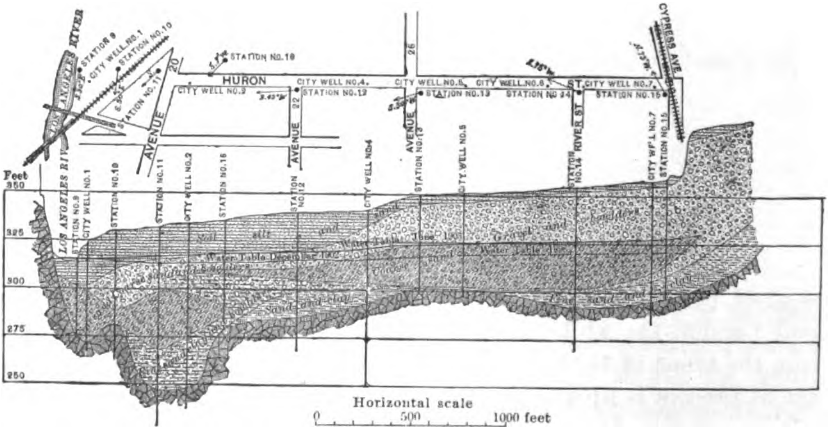
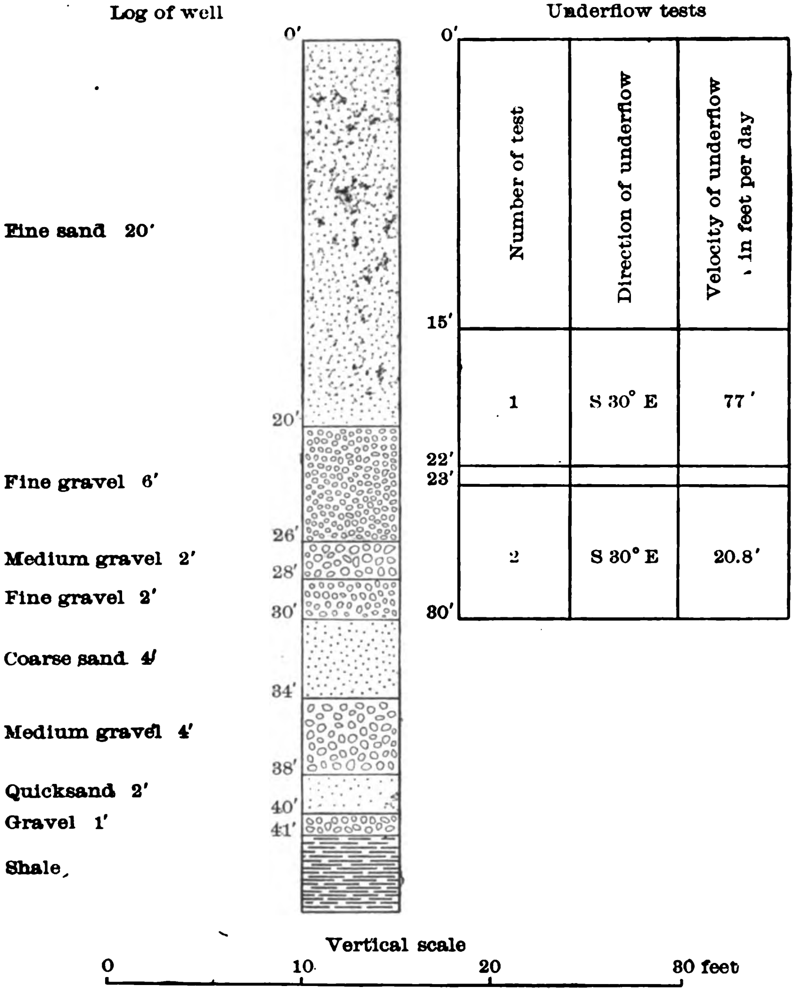


FIG. 22.—Huron street cross section.

STATIONS AND RESULTS.

The first test made was at station 9 (fig. 21), just above station 1. A group of well points was driven with a hand rig and tested between 15 feet and 23 feet. The direction of the underflow was S. 30° E., parallel with the surface stream, velocity 77 feet per day. The well points were then driven deeper and a test made between 22 feet and 30 feet, where the direction of the underflow was S. 30° E., velocity 20.8 feet per day. The order of the strata, record of the wells, and the velocity measurements are shown in fig. 23.

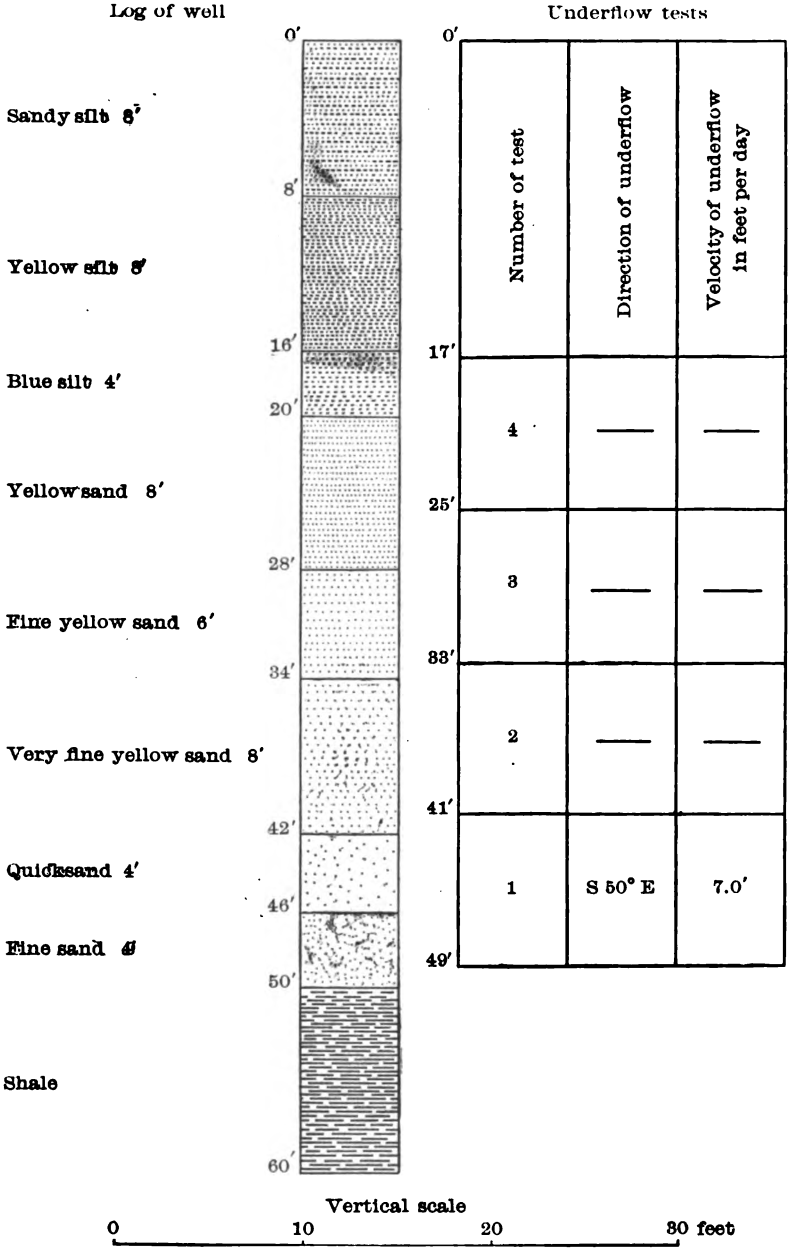
The ampere curve of the second test at this station is shown in fig. 11, a. It illustrates what form of curve may be expected with high velocities and shows that observations at intervals of a few minutes must be taken to correctly delineate such a curve. This is an extreme case, however. A test well was sunk by the hydraulic-jetting method here and the record of the wells is based on the material washed out of the drivepipe. The pipes broke when it was attempted to drive them beyond about 30 feet and no deeper tests were made.



Number of test	Direction of underflow	Velocity of underflow in feet per day
1	S 30° E	77'
2	S 30° E	20.8'

Fig. 23.—Underflow tests at station 9.

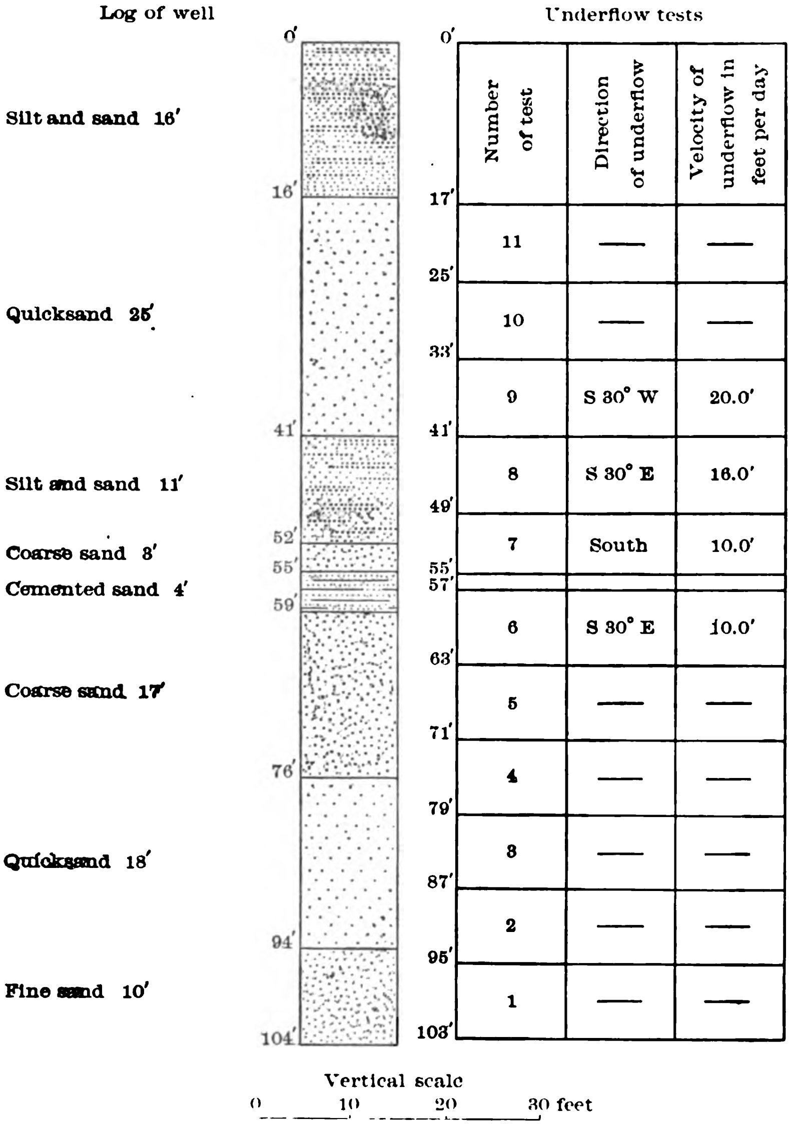
Station 10 is on the left bank of the river, as shown in fig. 21. This group of wells was sunk with a hand rig, using the heavy drive-pipe described on page 15. The first test was made between 41 feet and 49 feet. The direction of the underflow was S. 50° E., velocity 7



Number of test	Direction of underflow	Velocity of underflow in feet per day
4	——	——
3	——	——
2	——	——
1	S 50° E	7.0'

FIG. 24.—Underflow tests at station 10.

feet per day. It should be noted that the flow was probably through the stratum between 46 feet and 50 feet. Tests were afterwards made betweeen 33 feet and 41 feet, between 25 feet and 33 feet, and between 17 feet and 25 feet. but no underflow was detected. The

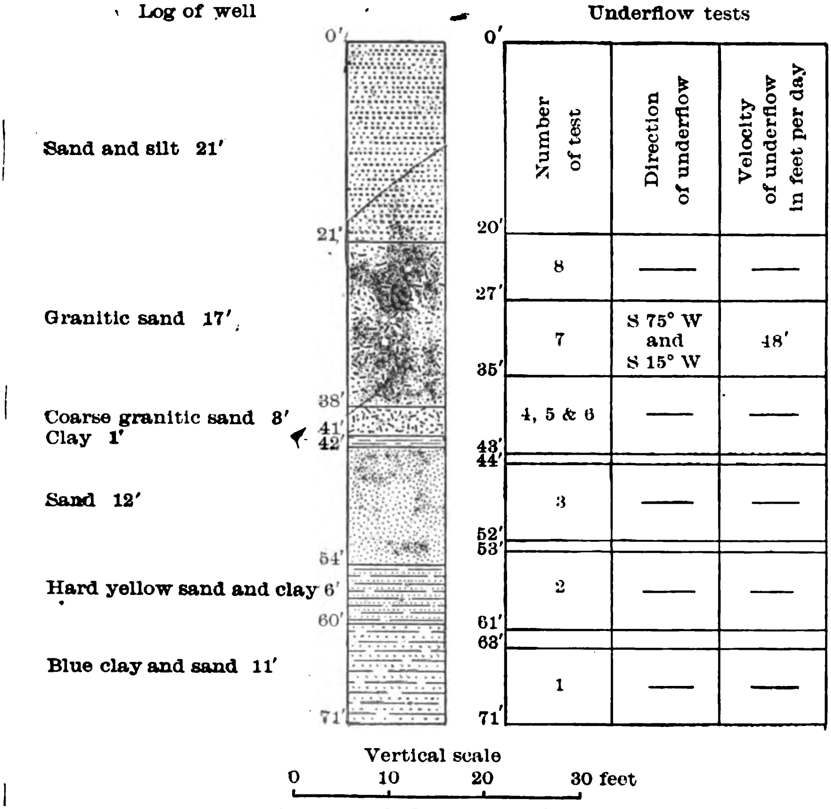


Number of test	Direction of underflow	Velocity of underflow in feet per day
11	——	——
10	——	——
9	S 30° W	20.0′
8	S 30° E	16.0′
7	South	10.0′
6	S 30° E	10.0′
5	——	——
4	——	——
3	——	——
2	——	——
1	——	——

FIG. 25.—Underflow tests at station 11.

material washed out of the drivepipe also indicated that the ground was practically impervious. The order of the strata, record of the wells, and the velocity measurements at this station are shown in fig. 24.

Station 11 is between the Southern Pacific Railroad and Avenue 20, as shown in fig. 21. One well of this group was sunk with the hand-rig and the rest by the well-driving machinery, as described on page 12. The first test was made between 95 feet and 103 feet, but the result was uncertain, the final conclusion being that there was no underflow at this depth. Other tests were made between 87 feet and 95 feet, between 79 feet and 87 feet, between 71 feet and 79 feet, and between 63 feet and 71 feet, but no underflow could be detected. The water from 63 feet to 104 feet was heavily charged with sulphureted hydrogen. A test was then made between 55 feet and 63 feet.



Number of test	Direction of underflow	Velocity of underflow in feet per day
8	——	——
7	S 75° W and S 15° W	48′
4, 5 & 6	——	——
3	——	——
2	——	——
1	——	——

FIG. 26.—Underflow tests at station 12.

The direction of the underflow was S. 30° E., velocity 10 feet per day. Another test was made between 49 feet and 57 feet. The direction of the underflow was due south and the velocity 10 feet per day.

This was followed by a test between 41 feet and 49 feet, where the direction of the underflow was S. 30° E., velocity 16 feet per day. The next test was between 33 feet and 41 feet, where the direction of the underflow was S. 30° W., velocity 20 feet per day. Two more tests were made, one between 25 feet and 33 feet and another between 17 feet and 25 feet, but no underflow was detected. The order of the strata, record of the wells, and the velocity measurements at this station are shown in fig. 25. The wide divergence in the direction of the underflow at this station, amounting to 60°, indicates that the water follows the most open strata.

Station 12 is at the intersection of Huron street and Avenue 22, as shown in fig. 21. Tests were made between 63 feet and 71 feet, between 53 feet and 61 feet, between 44 feet and 52 feet, and between 35 feet and 43 feet, but no underflow was detected. The next test was made between 27 feet and 35 feet, where the direction of the underflow was S. 15° W., velocity 48 feet per day, and also S. 75° W., velocity 48 feet per day, the underflow here apparently being through two porous strata in which the directions of movement diverge 60°. The last test was made between 20 feet and 27 feet, where no underflow was detected. The order of the strata, record of the wells, and the velocity measurements are shown in fig. 26. Below 50 feet the water was impregnated with sulphureted-hydrogen gas.

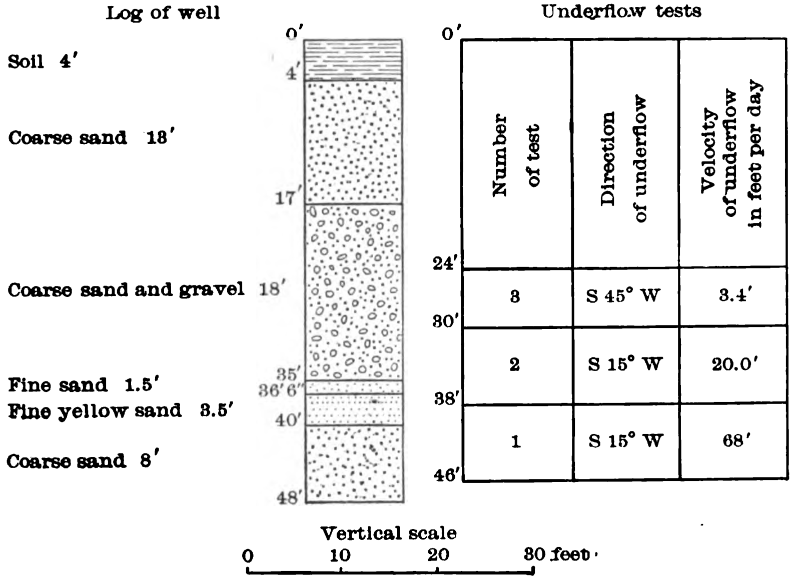
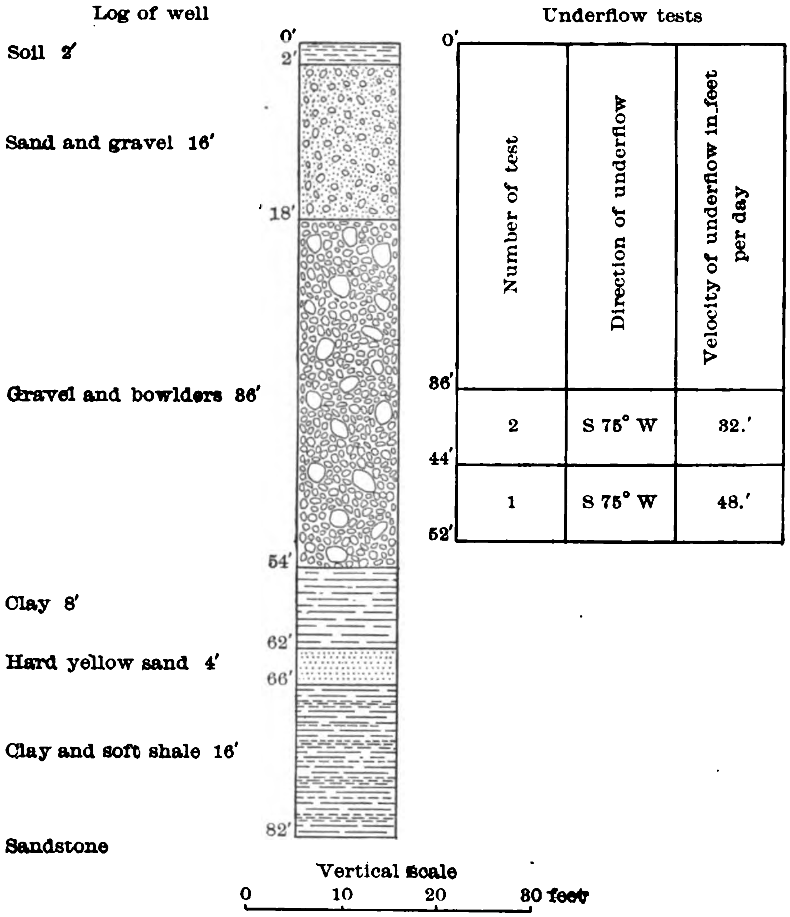


FIG. 27.—Underflow tests at station 13.

Station 13 is at the corner of Huron street and Avenue 26, as shown in fig. 21. A test was made between 38 feet and 46 feet, where the direction of the underflow was S. 15° W., velocity 68 feet per day. The next test was between 30 feet and 38 feet, where the direction of the underflow was S. 15° W., and the velocity 20 feet per day. The last test was between 24 feet and 30 feet, where the direction of the underflow was S. 45° W., velocity 3.4 feet per day. The order of the strata, record of the wells, and the velocity measurements are shown in fig. 27. Attention is called to the westerly direction of the underflow, due, without doubt, to the influence of the rising water table.

Station 14 is at the crossing of Huron street and River street, as shown in fig. 21. The first test was between 44 feet and 52 feet, where the direction of the underflow was S. 75° W., velocity 48 feet per day. The next test was between 36 feet and 44 feet, where the direction of the underflow was S. 75° W., velocity 32 feet per day. The top of the well screen being at about the level of the water plane before the rise due to the floods of the Arroyo Seco, it was decided to leave the pipes in the ground and test the direction and velocity of the underflow as the water table gradually falls. That it will fall is proved by the fact that the wells above are now lowering at about 1 foot per week. The order of the strata, record of the wells, and the velocity measurements are shown in fig. 28.



Number of test	Direction of underflow	Velocity of underflow in feet per day
2	S 75° W	32.'
1	S 75° W	48.'

FIG. 28.—Underflow tests at station 14.

Station 15 is at the eastern termination of Huron street, as shown in fig. 21. The first test was made between 45 feet and 47 feet, but

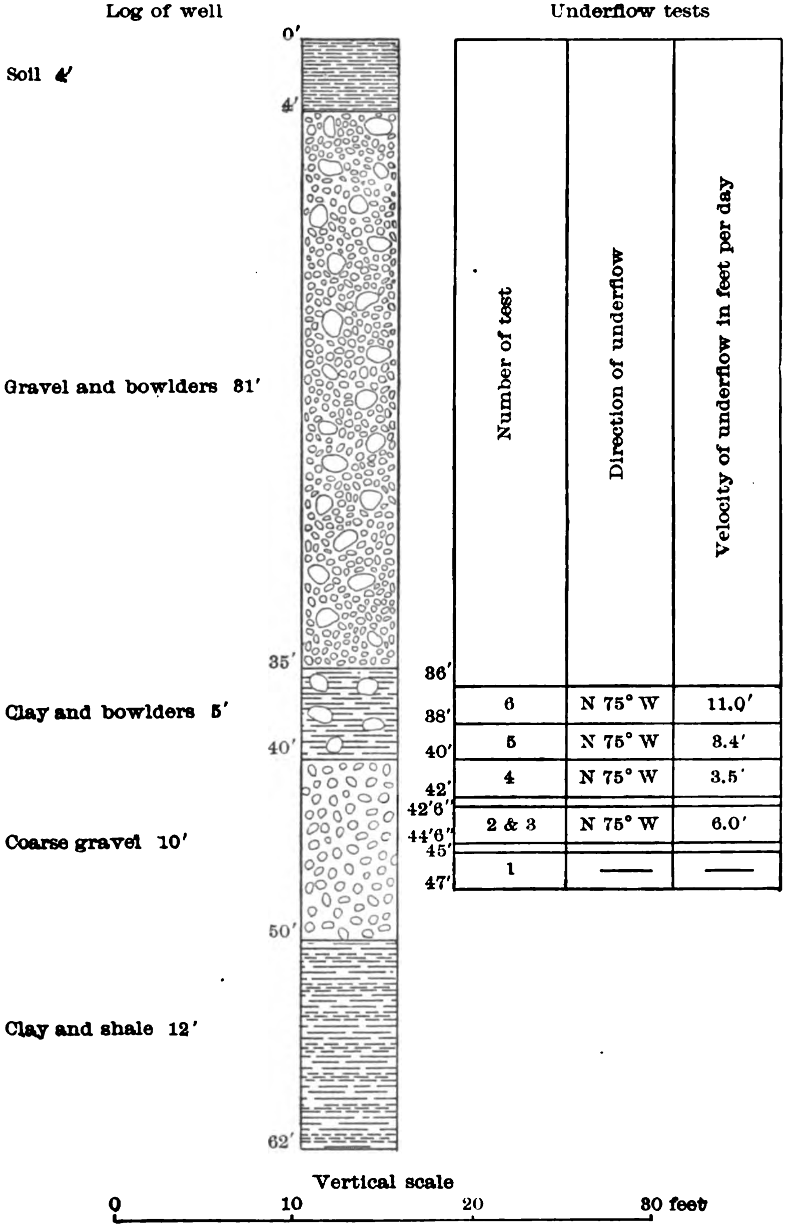
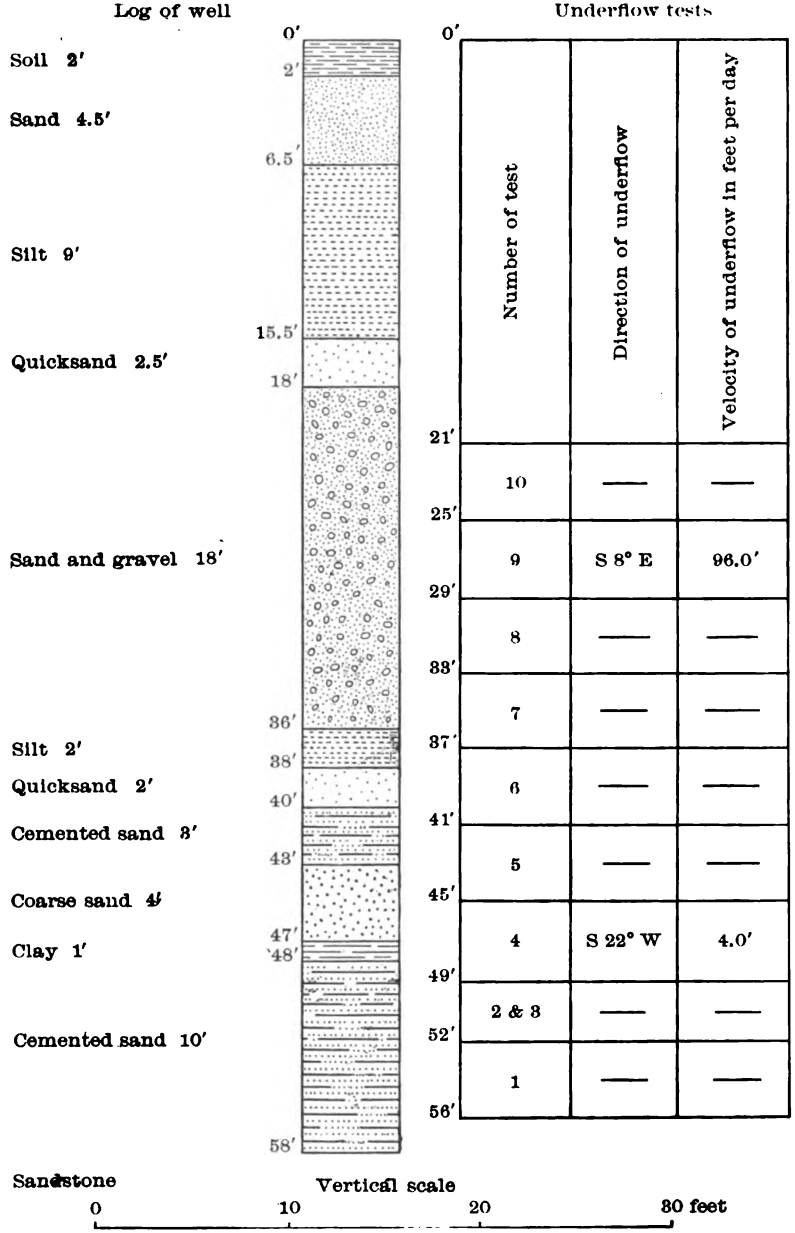


FIG. 29.—Underflow tests at station 15.

no underflow was detected. A test was then made between 42.5 feet and 44.5 feet, where the direction of the underflow was N. 75° W., velocity 6 feet per day. The next test was between 40 feet and 42 feet, where the direction of the underflow was N. 75° W., velocity



Number of test	Direction of underflow	Velocity of underflow in feet per day
10	——	——
9	S 8° E	96.0'
8	——	——
7	——	——
6	——	——
5	——	——
4	S 22° W	4.0'
2 & 3	——	——
1	——	——

FIG. 30.—Underflow tests at station 16.

3.5 feet per day. Another test was made between 38 feet and 40 feet, where the direction of the underflow was N. 75° W., velocity 3.4 feet per day. The last test was made between 36 feet and 38 feet, where the direction of the underflow was N. 75° W., velocity 11 feet per day. The order of the strata, record of the wells, and the velocity measurements are shown in fig. 29.

Station 16 is north of Huron street, between Avenue 20 and Avenue 22, as shown in fig. 21. Tests were made between 52 feet and 56 feet and between 49 feet and 52 feet, but no underflow was detected. The next test was made between 45 feet and 49 feet, where the underflow was S. 22° W., velocity 4 feet per day. Tests were then made between 41 feet and 45 feet, between 37 feet and 41 feet, between 33 feet and 37 feet, and between 29 feet and 33 feet, but no underflow was detected. A test was then made between 25 feet and 29 feet, where the direction of the underflow was S. 8° E., velocity 96 feet per day. The last test was made between 21 feet and 25 feet, but no underflow was noted here. The order of the strata, record of the wells, and the velocity measurements are shown in fig. 30.

Attention is directed to the probability of this well having penetrated both pervious areas in the Huron street cross section, as shown in fig. 22. All the ground tested here, except the two beds in which underflow was detected, seemed to be close-textured and practically impervious.

DISCHARGE AT HURON STREET.

Owing to the reversal in the normal direction of underflow, by the floods of the Arroyo Seco, it is not possible to estimate, except very approximately, the quantity of ground water passing the Huron street section. The observed facts are here presented, from which engineers may draw their own conclusions regarding the tests and value of the computations submitted.

The western and lower gravel bed, shown on the cross section, fig. 22, has a cross-sectional area of approximately 17,000 square feet, and the upper and eastern gravel bed has a cross-sectional area of about 30,700 square feet below the water plane of 1896. These figures are based on the results of the underflow tests, and on the assumption that all the cross section where flow was not detected has a velocity of underflow of 1 foot per day. The outline of the pervious sections was sketched from station to station.

The average of all the velocities observed in the western gravel bed is 20.6 feet per day, and the porosity is assumed to be 25 per cent. Using this data, the discharge from this portion of the section should be $17{,}000 \times 20.6 \times 0.25 = 87{,}550$ cubic feet per day. This discharge should be reduced by about 20 per cent to correct for the obliquity of flow across the section, $87{,}550 \times 0.8 = 70{,}040$ cubic feet, or 524,000 gallons per day, in round numbers.

The average of all the velocities observed in the eastern gravel bed is 30.9 feet per day. If it is assumed that under normal conditions the height of the water table is represented by the line marked 1896 in fig. 22, the area of the cross section through which flow takes place will be 30,700 square feet. The slope of the water table was not radically different in 1896 (the assumed normal condition) from what it was in 1903, when the underflow tests were made, but the direction of the flow in the eastern end of the section was deflected nearly or quite 90 degrees from the normal. It is assumed that since the degree of slope of the water table at these two periods is approximately the same, the velocity of underflow was not radically different. Under normal conditions, the direction of flow makes an angle of about 30 degrees with the line of Huron street. The computed discharge has been multiplied by 0.50, the sine of 30 degrees, to correct for the obliquity in the direction of the flow. The porosity is here assumed to be 25 per cent, as before. The discharge from this portion of the section should then be $30,700 \times 30.9 \times 0.25 \times 0.5 = 118,578$ cubic feet, or 889,000 gallons per day, in round numbers.

Although no flow was detected in the rest of the cross section, between the water table and bed rock, it can not be entirely impervious, and it is assumed that the average velocity is 1 foot per day. This is certainly a maximum, as many tests were continued long enough to detect as low a velocity as this.

If the average porosity is assumed to be 25 per cent as above, and the average direction of underflow is at an angle of 30 degrees with Huron street, the discharge from this section should be $60,000 \times 1 \times 0.25 \times 0.50 = 7,500$ cubic feet per day, or 56,000 gallons, in round numbers.

The total computed discharge from the Huron street section will then be 196,118 cubic feet per day, or 2.27 cubic feet per second.

The city tunnel has now been driven 1,163 feet under the river bed, one-fourth mile below. This tunnel yields about 7 second-feet when pumped for a short time at intervals of a few days. The supply from the tunnel has so far been drawn from the water stored in the gravels in the immediate vicinity, pumping not having as yet been continued long enough to demonstrate what the gravel beds will yield.

COST OF TESTS AT HURON STREET.

The following table shows the average cost of testing underflow at Los Angeles, Cal., for a period of two months, using the well-drilling machinery and testing apparatus described in this report:

Cost of underflow tests at Huron street, Los Angeles, Cal., from May 14 to July 14, 1903.

	Total expenses for 2 months.	Driving pipe.	Pulling pipe.	Testing.
Well driller	$150	$96	$22	$32
Laborers	100	64	14	22
Cook	70	40	10	20
Observer	150	....	....	150
Subsistence	120	50	20	50
Repairs	40	28	6	6
Chemicals	30	....	....	30
Fuel	8	6	2	....
Supervision	150	60	30	60
Total	818	344	104	370

Pipe driven, 989 feet; cost per foot, $0.348.
Pipe pulled, 929 feet; cost per foot, $0.111.
Total number of underflow tests, 16; cost per test, $23.125.
Total average cost per test, including driving, pulling, etc., $51.125.

The well-drilling machinery described was constructed in Los Angeles from designs furnished the foundrymen and from machinery purchased at local supply houses.

Cost of well-drilling machinery.

Cost of drilling rig in Los Angeles	$870.00
Two hundred linear feet of 3-inch, double, extra-heavy drive pipe, with taper-joint couplings, at $4 per foot	800.00
Total	1,670.00

SUMMARY.

The following suggestions are based on the experience gained during the work at Huron street and in the San Fernando Valley:

(1) The location of the section where it is proposed to test the underflow should be carefully studied. It should be, if possible, in a straight stretch of the valley, and at some distance, either up or down, from large tributary streams.

(2) The form and slope of the water table should be ascertained and the line of test stations placed most advantageously.

(3) In order to secure accurate results, the testing stations should be close together along the line of the section.

(4) The well screens should be short and the ground should be tested at each 2 to 4 feet in depth, down to bed rock when possible.

(5) If possible, the porosity of the pervious beds should be determined.

(6) When making deep tests some form of drive pipe and screen such as described on the preceding pages should be used.

(7) Recording ampere meter and switch clocks should be used.

The discharge from a given section will undoubtedly be far less than anticipated, the popular tendency being to greatly overestimate the amount of underflow. Even if the results attained by this method of testing are not as accurate as desired, they are, nevertheless, of great value, as they enable investigators to compute, approximately, what could only be roughly estimated before.

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Water-supply and irrigation papers.

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U. S. Dept. of the Interior.

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U. S. Geological survey.

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Water-Supply and Irrigation Paper No. 113 Series L, Quality of Water, 8

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE DISPOSAL OF
STRAWBOARD AND OIL-WELL WASTES

BY

ROBERT LEMUEL SACKETT

AND

ISAIAH BOWMAN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., *January 27, 1904.*

Sir: I have the honor to transmit herewith two manuscripts, the first entitled "Strawboard Waste: Its Damage to Water Resources and its Economic Disposal," by R. L. Sackett; the second, "Disposal of Oil-Well Wastes at Marion, Ind.," by Isaiah Bowman, and to request that they be published together as one of the series of Water-Supply and Irrigation Papers.

These papers include a part of the results of investigations made by the division of hydro-economics. The determination of the quality of available waters in the United States and their applicability to domestic and industrial uses involves a consideration of the principal sources of their pollution.

The subjects dealt with in these papers represent two particularly troublesome sources of damage to water resources. The areas in which such damage occurs are very large and important, pollution of the kind considered in the first paper covering the States of Ohio, Indiana, and Illinois, and that discussed in the second paper having been felt in all those parts of the country in which oil wells have been developed.

These investigations were undertaken in an experimental way, and it is hoped that they may serve to direct wider attention to the problems involved, to the end that practical solutions may be reached which will be satisfactory to all those whose interests are involved.

Very respectfully,

F. H. Newell,
Chief Engineer.

Hon. Charles D. Walcott,
Director United States Geological Survey.

STRAWBOARD WASTE: ITS DAMAGE TO WATER RESOURCES AND ITS ECONOMIC DISPOSAL.

By ROBERT LEMUEL SACKETT.

INTRODUCTION.

Rivers and streams have a commercial value by which they have been universally rated, yet in many cases this rating must properly take into account more than strictly commercial or industrial uses. Water power or shipping facilities have often determined the location of a mill where a city was unforeseen, and the value of the stream as a source of water supply for culinary or drinking purposes has thus often been left entirely out of consideration. But watercourses contribute not only to the commercial value of a location, but to health, and their influence on health has now become an important factor in determining the money value of the lands bordered by them. Health and wealth are in some localities dependent on the condition and flow of streams.

All sanitary authorities now recognize the vital necessity of providing a pure source of municipal or private water supply. Family wells and springs can safely serve but a small proportion of the population. The urban population is now about 50 per cent of the total, and as it grows the percentage dependent on municipal supply will increase. It is to this class of water supplies that this discussion is confined.

SOURCES AND EFFECTS OF STREAM POLLUTION.

SEWAGE POLLUTION.

As the wilderness was subdued by the pioneer, small mills and towns were established on lakes, rivers, and streams. By cutting the forests and draining the cultivated and settled areas the character of the stream flow was changed. Forests are natural reservoirs, where the rainfall is stored, to be given up gradually. Cultivation and drainage aid in producing a rush of water to the streams after rains, which is followed by a period of very low flow in a dry season. The villages in time become cities, drawing their water supply from, and discharging their sewage into, the near-by stream. This source of pollution, in connection with the occasional very low stream flow and consequent slight dilution, has been the cause of great commercial loss, of widespread disease, and of death.

POLLUTION BY TRADE WASTE.

But city sewage is not the only source of stream pollution, for many industries discharge large quantities of refuse, called "trade waste," the presence of which in sewers and streams is very objectionable from a sanitary point of view.

On the continent of Europe and in Great Britain this subject has received considerable attention. The English rivers pollution act of 1876 treats the matter at considerable length, and gives city authorities power to require the adoption of remedial measures by offending factories. In the United States the necessity for legislation restricting pollution by trade waste has only recently arisen. Among the States that have already acted upon this question Massachusetts stands first.

The waste from industries is divisible into three classes—animal, vegetable, and mineral refuse, though many factories discharge two and even all three kinds.

In the first class of waste is included that from abattoirs, packing houses, tanneries, and woolen mills, which discharge large quantities of animal tissue and oil. The decomposition of this matter may be slow, and if deposited on flats it causes unpleasant odors and attracts vermin. If afloat in such quantities that the dilution is not sufficient, the water is dangerous for house use, and even cattle refuse to drink it.

To the second class belong the quantities of vegetable matter which escape from distilleries and from paper, wood-pulp, and strawboard mills—matter for which no present economical use has been found.

To the third class belong the wastes from oil refineries and gas works, which run off mineral oils and heavy tars. When discharged into city sewers these have proved very objectionable, and when discharged into sluggish streams they lodge on shoals and flats with the rise and fall of the water level, coating and killing vegetation, causing unpleasant odors, and fouling the water for dairying and other purposes. Tin-plate and rod mills and galvanizing and plating works discharge large quantities of chemical waste, such as dilute sulphuric or hydrochloric acid, copper sulphate, and sulphate and chloride of iron.

Among other local industries that produce serious nuisance in their vicinity are soap factories, factories using the Solvay ammonia soda process, and white lead, paint, varnish, and starch factories. Certain mineral waters used for curative and bathing purposes and the drainage from mines may also be offensive, but these are not usually amenable to pollution laws. In England they are specifically excluded in the rivers pollution act of 1876. In Pennsylvania the higher courts have passed upon a case involving mine drainage, and the operators were allowed to continue the natural drainage of the mine.

The effect of wastes upon the condition of the stream depends on the relative volumes of stream and of waste, the strength and character of the polluting material, and the proximity of other industries or of cities requiring pure water and of agricultural lands and residents who might declare a nuisance. It is clear, then, that no general rules can be laid down, but that each case of pollution must be decided on its own merits.

The addition of quantities of organic matter to a stream is highly objectionable, as it furnishes food for the rapid multiplication of disease bacteria which may be present, and it may cause a nuisance by slow decomposition by deposit upon shoals, tidal shores, and flats. Besides rendering the water impotable, abnormal amounts of organic matter cause serious damage to many purifying industries, to sugar factories, meat-packing houses, and canneries. The discharge of mineral waste, unless very highly diluted, hinders the natural purification of the stream, and adds substances that oxidize slowly. This waste kills fish and makes the water distasteful, foul smelling, and dangerous even, to cattle, thus interfering with important agricultural interests and increasing the menace to human life.

MANUFACTURE OF STRAWBOARD.

This report is confined to a careful study of the process of manufacture of strawboard (or pasteboard, as it is commonly called), to the character of the refuse, the nature of the pollution, the damage produced, and the possible means of preventing the pollution.

The principal factories of strawboard in the United States are confined to a comparatively small area. In the report of the United States census for 1900 59 factories are recorded as making strawboard. From 157,534 tons of raw material they produced a finished product valued at $3,187,342. Indiana led with 70,081 tons of board, worth $1,350,636. Ohio ranks second, with 40,531 tons, worth $800,038, and Illinois is third, with 20,100 tons, valued at $382,454. New York, Maryland, and Michigan rank next in order. The first three mentioned make 83 per cent of the board produced in the United States, and Indiana alone produces nearly 50 per cent of the total. The straw used in Indiana cost about $3.90 per ton, and the finished product was worth about $19 per ton.

The strawboard industry does not, of course, include the manufacture of wood pulp, sulphite fiber, or jute.

COMPOSITION OF STRAW.

Strawboard is manufactured from rye, wheat, and oat straw. In England a special straw, known as esparto grass, is used in making paper. Rye and wheat straws are preferred, as they yield the largest per cent of cellulose—the basis of all vegetable fiber. The chemical formula for cellulose is $n(C_6H_{10}O_5)$. The composition of various straws as given by Müller,[a] a German authority, is as follows:

---

[a] Jour. Soc. Chemical Industry, February 28, 1894, p. 101.

TABLE 1.—*Composition of straws.*

	Winter rye.	Winter wheat.	Summer barley.	Winter barley.	Oats.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Water	14.3	14.3	14.3	14.3	14.3
Organic constituents	82.5	80.2	79.7	80.2	80.7
Ash	3.2	5.5	....	5.5	5.0
Cellulose	54.0	48.0	43.0	48.4	40.0

James Beveredge, of Northfleet Paper Mills, Kent, England, gives[a] the following results of analyses of straws:

TABLE 2.—*Composition of straws.*

	Zealand wheat.	Dutch wheat.	Dutch oats.	Dutch rye.	Dutch barley.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Water	8.2	12.5	11.2	7.8	11.0
Organic constituents	44.2	43.6	46.0	49.3	47.7
Ash	10.0	7.5	5.5	1.8	7.2
Cellulose	37.6	36.4	37.3	41.3	34.1

In table 1 the organic constituents include cellulose; in table 2 they do not. In the latter the cellulose is unbleached.

Remsen gives the following percentages of cellulose, the straws being in the air-dry state. Rye straw, 54; wheat straw, 48; oat straw, 40. The differences appearing in the above tables are due to differences in the definition of cellulose, in the dryness of the materials, and in the various methods of separation employed. The order of the commercial rating of straws, as given by the strawboard companies, is as follows: (1) rye, (2) winter wheat, (3) spring wheat, and (4) oat. There is generally reckoned a loss of about 40 per cent by weight from the dry straw to the finished board, the latter containing from 5 to 8 per cent of moisture. Various factors enter into the percentage of loss. Straw purchased at harvest time contains a larger percentage of moisture than it contains some months later. The loss of weight from harvest to Christmas time amounts to almost 25 per cent, says an authority in the Journal of the Society of Chemical Industry.[b] Straw grown on light, sandy soils has a much lower specific gravity than that grown on heavy clay or mixed soils. Differences are also caused by weather conditions at harvest time. A wet straw causes greater loss

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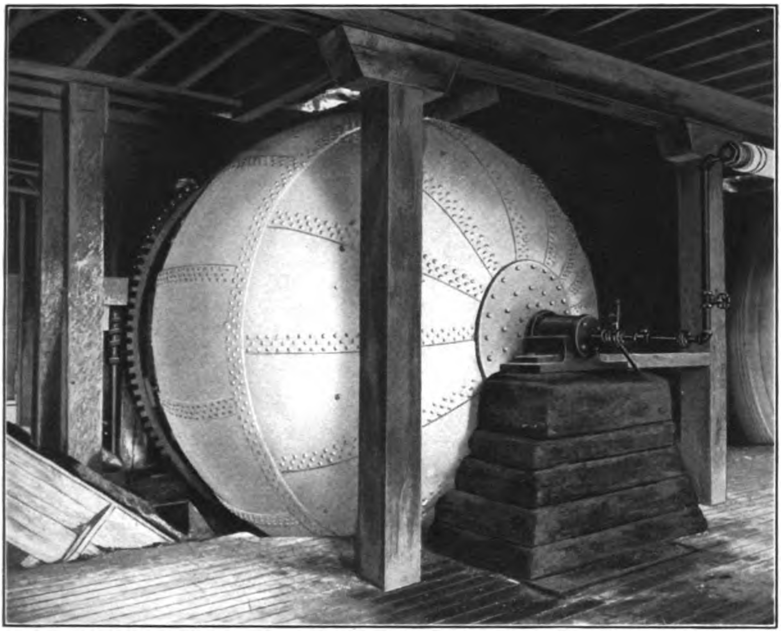
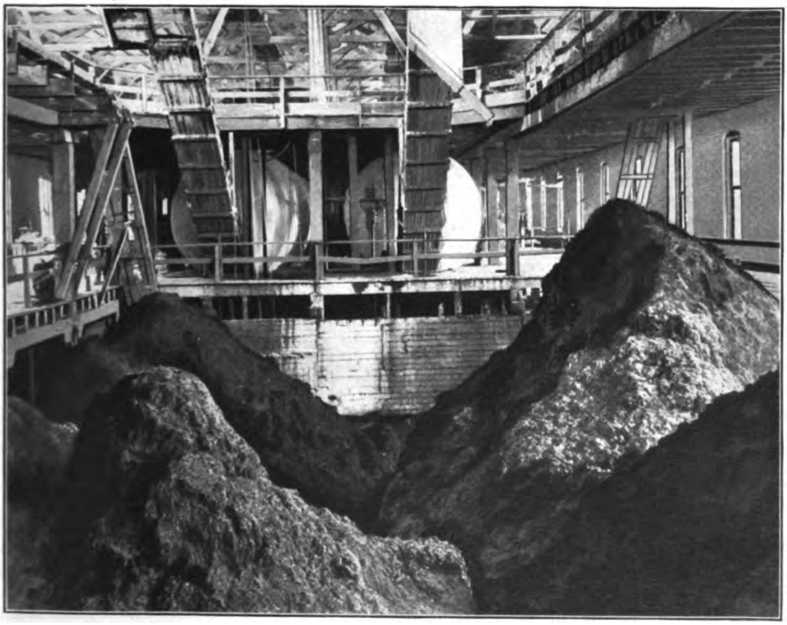
[a] Jour. Soc. Chemical Industry, February 28, 1894, p. 101.

[b] For February 28, 1901, p. 148.



A. STRAWBOARD ROTARIES.



B. ROTARIES AND STOCK PILES.

and makes a poorer quality of board. The driest material comes from that in the lofts of barns, while straw from stacks is usually damp. It is stated that baled straw is more moist than loose straw.

Of the 48 per cent of cellulose in wheat straw, about 30 per cent is saved by present means of manufacture of strawboard. The machinery and methods employed have not changed materially for many years, and there seems to be little prospect of greater economy being practiced. The reasons for this are discussed later in this paper.

STEAMING IN ROTARIES.

The process employed in the United States is as follows:

The straw is first subjected to a cooking process by steam and lime. A large ellipsoidal rotating steel boiler called a "rotary," shown in Pl. I, *A*, is filled with straw, which is then cooked down with steam, then again filled and cooked down until the rotary boiler has been completely filled. The process of filling a rotary occupies from six to twelve hours. The final charge consists of about 6 tons of straw and 30 bushels, or 2,100 pounds, of lime in the form of milk. This mixture is then rotated and cooked under 40 pounds of steam pressure for twelve hours. Pl. I, *A*, shows the steam line extending through one of the trunnions and the worm gear which rotates the cylinder. This apparently severe chemical and mechanical action results in a rapid softening of the woody fiber and in the reduction of the straw to a dark-yellow, pulpy mass. This "stock," as it is called, is stacked in piles 10 to 15 feet high to drain. Concerning the action which takes place in the rotaries, the Journal of the Society of Chemical Industry says:[a]

> The chemical action of the milk of lime on the encrusting materials surrounding the straw fiber is not a vigorous one. These encrusting materials are not completely, nor indeed to a great extent, separated from the cellulose. The mineral matter remains in the product practically untouched, and if any less quantity than that corresponding to the percentage in the original straw operated upon exists in the prepared pulp, it is due rather to the washing after digestion than to any solvent action of the milk of lime. Milk of lime under certain conditions has a bleaching action upon the straw. It neutralizes the organic acids usually found when fibrous plants are heated for any length of time in the presence of water.

The yield of pulp at this point will be from 75 to 80 per cent of the weight of the original material.

Pl. I, *B*, shows the rotaries, charged from the floor above, and the elevators that carry the stock from the rotaries and dump it in the piles shown in the foreground. At the extreme left is an endless-chain elevator which carries the stock to the beater room.

The material is allowed to stand in these piles for twenty-four hours or more to drain. After it is thus drained it contains about 50 per cent of water and from 6 to 7 per cent of lime. This is equivalent to from 12 to 14 per cent of lime in the dry straw. Since the original charge of lime and straw was in the proportion of 2,100 pounds of lime to 14,100 pounds of straw and lime, or about 14 per cent lime, practically none of the latter has drained out with the condensed steam. This drainage from the stock piles forms but a small part of the waste sewage. It is straw colored and very turbid, carrying a small quantity of fiber broken fine in the rotaries.

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[a] For February 28, 1894, p. 101.

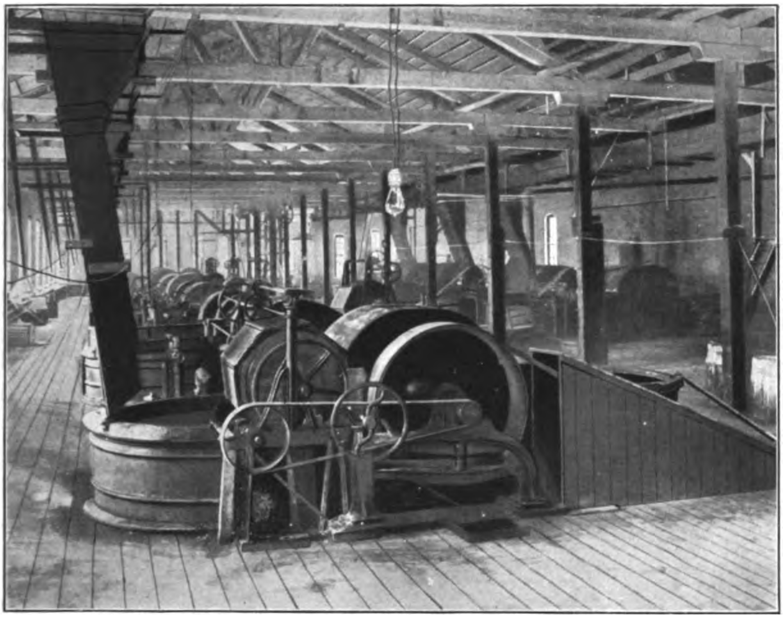
WASHING.

This process is much more drastic, and it is here that the great volume of waste is produced.

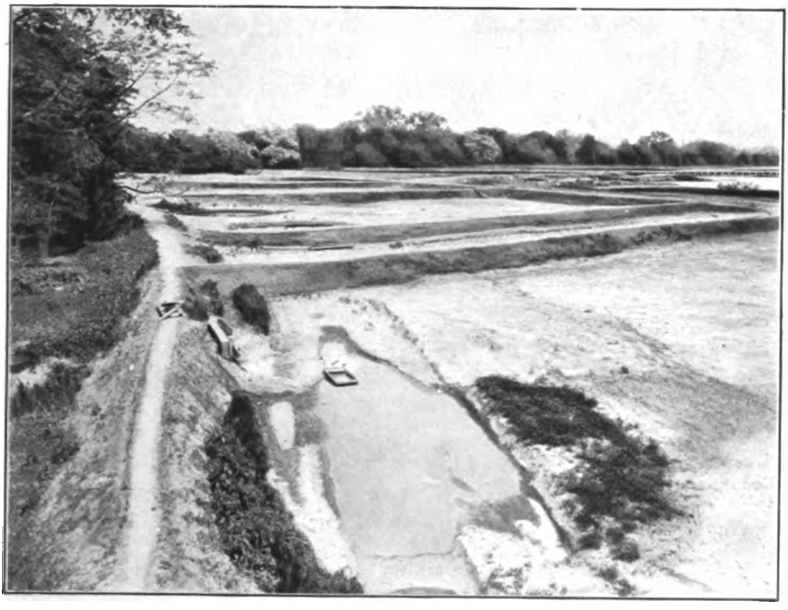
The stock is run through washing machines for the purpose of removing the lime. A row of washers in operation is shown in Pl. II, *A*. At the left is the chute from the conveyor above, down which the stock is fed. To the right of the chute are the water pipes. The washing machine consists of an oval channel about 3 feet wide, around which the stock travels, being supplied with copious volumes of water. Across this channel is placed a cylinder, 42 inches in diameter and 42 inches long, having longitudinal ribs or flanges about three-fourths of an inch square in section and three-fourths of an inch apart. Meshing with this, like the teeth of geared wheels, is an idler, below, of similar size and form. These wheels, revolving, lift the water and straw to a level several inches higher than that in the oval channel, whence it flows by gravity halfway around its course to a point where it meets a revolving brass screen of fine mesh, through which a part of the water escapes, carrying with it the finer particles of fiber and free lime. The remaining straw, with additional volumes of fresh water, now passes many times through the rolls, which further mash and break the fiber, and around to the screen, where more straw, lime, and water escape. The total waste is enormous. It now takes about 40,000 gallons of water to wash 1 ton of straw. About 3,200 pounds of straw and 560 pounds of lime are required to make 2,000 pounds of board. A small amount of lime remains in the board; hence 1,200 pounds of straw and about 500 pounds of lime are washed out by the 40,000 gallons of water. An idea of the volume of waste may be conveyed by giving the capacity of an average mill. Such a plant uses 50 tons of straw and nearly 10 tons of lime during every twenty-four hours. From 1,000,000 to 2,000,000 gallons of water are employed in the rotaries, washers, and vats. This volume of water carries away with it about 19 tons of the straw and practically all of the 10 tons of lime each twenty-four hours.

DRYING.

After the washing process the straw, with a considerable volume of water, is led to a train of rolls, consisting of three parts—first, the wet end; second, the hot rolls; third, the trimming and cutting machine. As it comes from the washers the material is run into vats,



A. PULP WASHERS.



B. SETTLING BASINS.

where it is mixed with large quantities of water and passed over hollow cylinders having fine wire-cloth faces, which allow the water to escape, leaving the fiber on the surface of the cylinder. The fiber is then taken by woolen felts, which are pressed down on the surface of the cylinder. This makes a web of paper on the felt. The pulp, which is now about one-third straw and two-thirds water, travels up and down, over and under a double train of hot rolls, heated by steam that is carried in through hollow bearings. As the pulp passes on through the train it is constantly pressed and dried, until finally it is separated from its cloth support and goes to the trimming machine, where it is cut into sheets of proper size. It now contains about 10 per cent of water and a small quantity of lime. The board is manufactured in many thicknesses and weights. Just before it is trimmed it may be coated on one or both sides with a thin paper facing or finish.

METHODS OF DISPOSAL OF WASTE.

The waste liquors from the rotaries and washers, and that from the vats where it is not used over again in the washers, are run together and discharged into a trough or ditch, leading in some cases to a neighboring stream. The effect of these wastes upon the stream depends upon its character and volume. As many Indiana rivers flow over limestone beds, their water is hard, carrying 15 to 20 grains of lime per gallon. But the waste liquor from a strawboard mill contained in one case a minimum of 66 grains per gallon (an amount which has recently been doubled by a decrease in the quantity of water used), and in some cases, where wash water is not plentiful, the quantity of lime reaches 200 or more grains per gallon. In order to reduce the quantity of lime to 40 grains per gallon the minimum stream flow would need to be about ten times the volume of water employed in the process. This would require a stream that discharged, in time of drought, from 10 to 20 million gallons in twenty-four hours. This limits the number of streams upon which such mills can be operated in the present manner without nuisance, to a few rivers in each State.

On account of the clearing of forests, artificial drainage, and irregularities of rainfall the flow of Indiana tributaries becomes extremely low in the late summer and fall. Some, indeed, cease to be more than isolated ponds, the water seeping through the gravel beds. Under these circumstances, if not under normal conditions, the discharge of sludge into a stream produces results that demand very serious consideration. The straw waste, when deposited on flats from which the water has receded, decomposes very slowly, its decay being in part retarded by the presence of lime and silica. Remsen says that as much as 73 per cent of the ash of wheat straw is silica. As the analyses given in table 4 (p. 27) show, the quantity of ammonia present in the waste is very large, and this is undoubtedly the principal cause of the very slow decomposition.

At some places the solid part of the waste has been heaped on large tracts of land. In these cases the stench produced has been carried by the wind for a considerable distance, causing a nuisance.

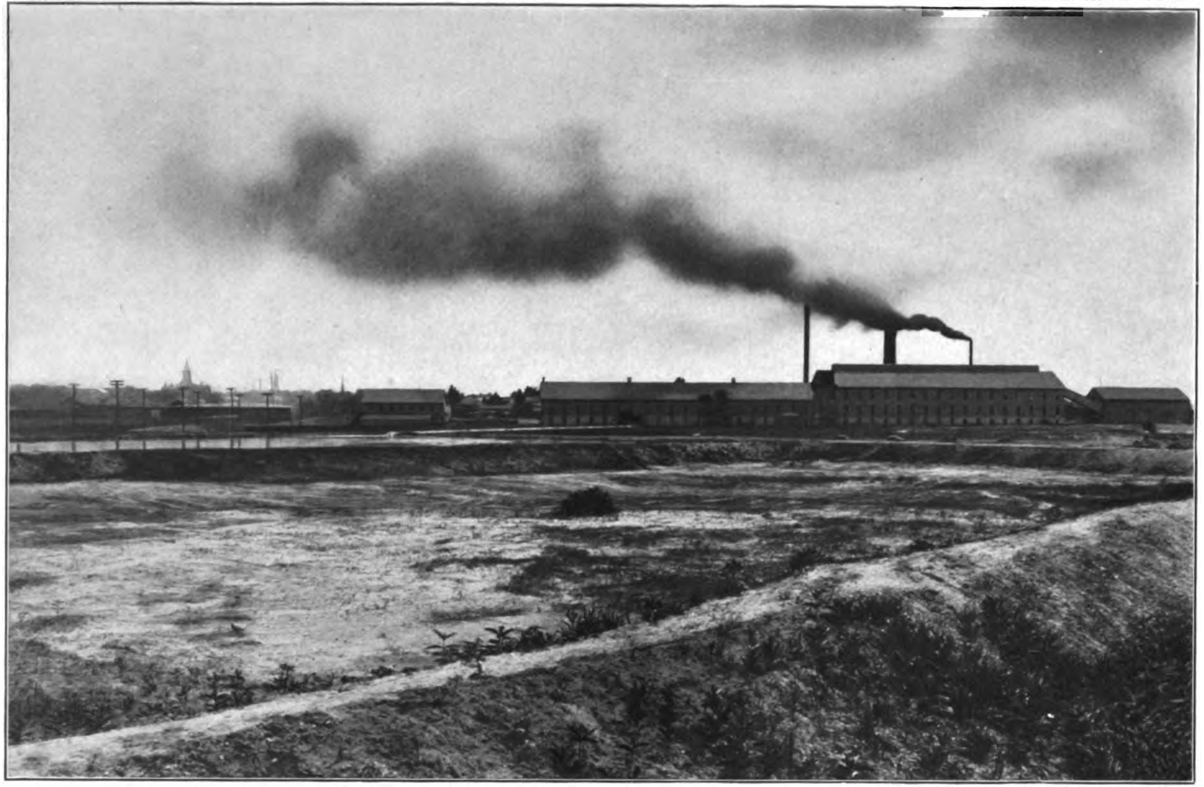
Mr. Sweeney, commissioner for fisheries and game for Indiana, in his biennial report for 1901 and 1902, speaking of the conditions which tend to destroy fish, says, on page 11:

> Greater than all other artificial means is the pollution of our streams with the refuse from strawboard mills, oil wells, and pulp mills. This refuse covers the spawning beds and prevents the eggs from hatching, while it penetrates the gills of the living fish and kills or drives them from the streams.

The quantity of lime would in some cases be such as to kill the fish if the straw did not. Game fish are not to be found in polluted waters. Thus the interests of the State enter into the question of stream pollution by strawboard mills.

In other cases the method of disposal has been modified by running the waste into a series of beds scooped out of a gravel bottom land. Here the straw and lime slowly settle, the water filtering through the subsoil and finding its way to the neighboring creek. But the great quantity of straw waste soon clogs such natural filters as have been tried. High water is depended on to wash the refuse out of the beds, whence it is deposited on other lands below; so that the method is only a makeshift.

What a carefully constructed settling and filtering plant may accomplish has not yet been determined. During the summer of 1903 the American Strawboard Company built at one of its factories a series of basins, shown in Pl. II, *B*, Pl. III, and fig. 1. Basins Nos. 1 to 5, fig. 1, average an acre each, while No. 6 is about 2 acres in area. Levees from 4 to 6 feet high were built, so that the basins could be filled to a depth of about 5 feet. From the old ditch which is shown in fig. 1 a spout was constructed to conduct the waste into basin No. 1. From this basin it flows diagonally to a weir at the opposite corner, where it enters basin No. 2. The flow is diagonally across each basin to the next in order through the series, to No. 5 or No. 6. From basin No. 5 a gate leads to filter No. 1, and from basin No. 6 a similar gate leads to filter No. 2. These filters have lines of 8-inch tile laid 25 feet apart and covered with 2 feet of gravel. The underdrains lead to the open ditch between the two filters. Each basin has a gate leading to the river, so that the waste can be run through any number of settling basins and then into the river or through the filters. The waste was turned into basin No. 1 in the early summer. When it had filled, the overflow ran into basin No. 2, and so on, basin No. 6 being filled in late summer.



SETTLING BASINS AND FILTER BEDS.

It seems inevitable that in time there will be a large deposit of straw and lime, which will have to be scraped off the basins and filters and carted away. Seepage through the walls and bottoms of the basins will decrease and the filters will clog until the efficiency has reached an unsatisfactory point. The period of time which will elapse before this condition arises and the effectiveness of months of sedimentation, with or without filtration, will not be known until a season has passed.

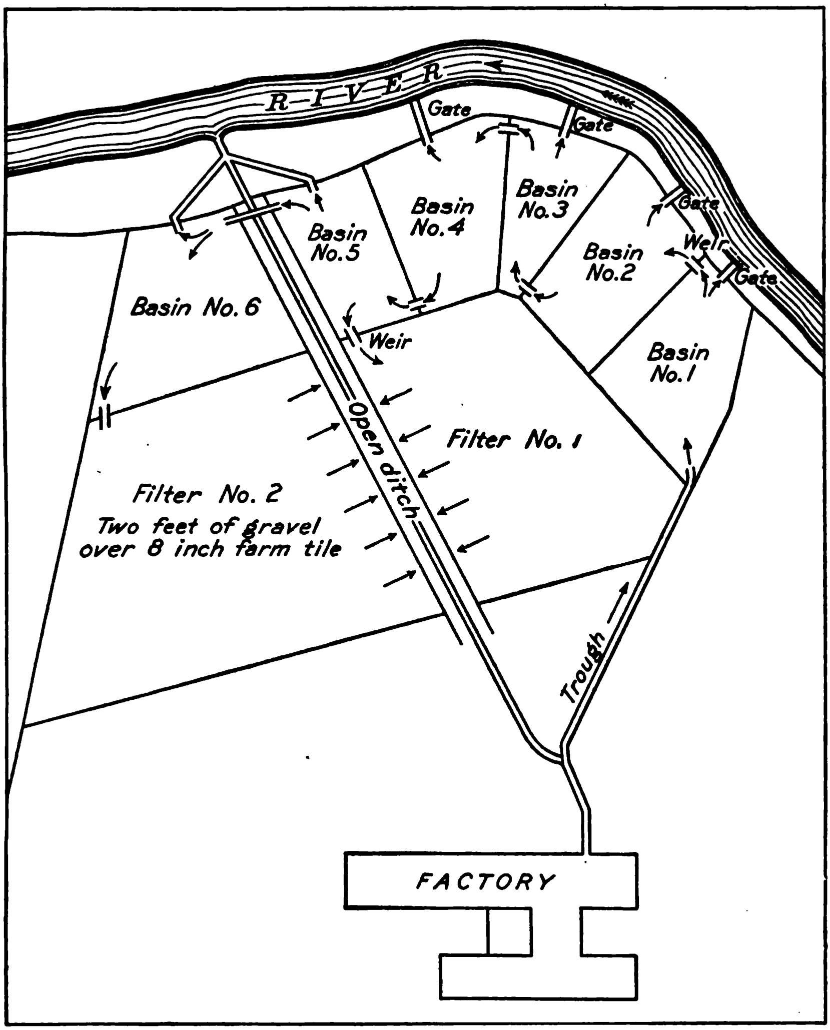


FIG. 1.—Plan of strawboard settling basin.

At one of its plants the American Strawboard Company used a trough-shaped device for separating the fine straw from the waste water. A vat 16 feet long was constructed, the end view of which was practically an equilateral triangle. The waste as it came from one of the washers was discharged into this vat, so that the water started downward, then turned upward through a screen, leaving the straw to continue downward. The screens clogged in the course of time and had to be cleaned by hand. The vat held about 7,000 gallons and treated 70,000 gallons in twenty-four hours.

As the waste passed from the washers to the vat the analysis was as indicated in the first column, and the analysis as the water came from the vat is recorded in the second column.

Analyses of strawboard waste before and after passing from washers to vat.

[In parts per 100,000.]

	Before.	After.
Suspended matter:		
Organic matter	565.7	188.6
Inorganic matter	393.1	123.3
Total residue	958.8	312.5
Total solids:		
Organic matter	1,294.5	528.5
Inorganic matter	661.8	244.3
Total residue	1,956.3	772.8
Calcium	510.5	204.8

It will be seen that the vat removes about 66 per cent of the suspended matter. The latter is, however, abnormally high, and the effluent still contains 312.5 parts per 100,000—five to ten times what it should before passing to a stream. Increasing the size of vat and decreasing the rate of flow, with some changes of design in order to emphasize the upward-flow principle, might lead to a design which would be sufficient where the stream flow and dilution were high.

No bacterial treatment such as is employed in the purification of sewage will avail in this case, as the treatment with lime and steam in the rotaries destroys all the bacteria present. A considerable period must elapse for the cultivation of such organisms.

EXPERIMENTS ON DISPOSAL OF WASTE.

To determine the possibility of other and more efficient methods of disposal than those just outlined, the author was appointed to take charge of a series of experiments on strawboard waste and to report their results to the United States Geological Survey. His instructions were to study the process of manufacture, analyze the waste liquor, and find the efficiency and cost of various methods of disposal, in order that some recommendation might be made to the authorities or to the manufacturers when circumstances should demand a change in the method of disposal.

The expense is a very important item, as it is easy to find a method of treatment by which the waste can be purified, but the cost would prevent the operation of the mill. Other methods will clarify the waste, but leave the water extremely hard, thus accomplishing but half the purpose. Theoretically, the liquid which eventually flows into the stream ought not to be harder than the normal stream—a condition extremely difficult to fulfill by commercial methods. Likewise, the total solids should not be above an average amount contained in natural waters.

METHODS OF PURIFICATION.

There are three general methods of treatment for the purification of polluted water—sedimentation, filtration, and chemical precipitation.

SEDIMENTATION.

This process consists of letting the liquid stand for a period of time long enough to allow the matter held in suspension to settle to the bottom. There is no chemical action involved, but since organic as well as inorganic matter may be settled, future chemical changes are possible. The hardness or acidity will not be changed. The rapidity and efficiency of the process depend on the specific gravity of the suspended matter. Silt will settle quickly, and this process is frequently used to remove such objectionable material from water supplies.

In the case of strawboard wastes, the particles of straw are so fine and the specific gravity is so slightly above unity that the downward motion is very slow. A jar 10 inches high will settle about 10 per cent of its solid matter in twenty-four hours. In twenty-four hours more the change is very slight. At the end of twenty-four hours, color, turbidity, odor, and taste are about the same as before such treatment. The storage capacity required for twenty-four hours' settling would be twice the capacity of the mill. To settle forty-eight hours reservoirs that would contain three times the volume of refuse would be required, and so on. From 2,000,000 to 4,000,000 gallons' storage would be needed for such treatment.

Even with still longer periods of sedimentation the hardness would remain practically unchanged, as the only lime precipitated would be due to the CO_2 absorbed from the atmosphere.

FILTRATION.

The process next to be described, and one now very frequently used in the purification of water supplies and of sewage, is filtration. The water is allowed to pass slowly through a bed of charcoal, coke, furnace slag, or sand. The process is partly a screening one, but under proper conditions a very efficient bacterial action takes place, in which the healthful bacteria assist in reducing the organic matter to its constituent elements. *Bacillus coli-communis*—the biological index of sewage pollution—disappears, and not only suspended matter but the amount of chlorine is reduced, and the number of bacteria per cubic centimeter is decreased by from 95 to 99 per cent of the number present in untreated water.

There are two kinds of filters, mechanical and slow sand filters. In the former the rate of flow is higher and frequent cleansing is necessary, while in the sand bed the rate of filtration is much less and the filter purifies itself in part while resting or while in action. If the surface becomes clogged, occasional rakings are necessary in order to remove the clogged surface and restore it to its normal state.

CHEMICAL PRECIPITATION.

In this process the liquid is treated with a previously determined quantity of some chemical which will cause a reaction involving the production of a solid in the form of grains or flakes. As the precipitant has a specific gravity greater than water, it falls and drags down with it other solids. The rapidity of its action depends on the proper proportioning and mixing of the agents employed and on the weight of the particles and their size. A flocculent, heavy precipitate rapidly carries down with it a large proportion of the organic and inorganic matter that has been held in suspension.

Such processes are usually continuous; the fluid to be treated and the reagent are automatically mixed and fed in at the bottom of the tank, the current being upward. The purified liquid is taken from the top of the tank and the precipitated sludge is drawn from the bottom. Certain limitations have been found in the successful operation of the upward-flow principle. Hans Benedikt, in Die Abwasser der Fabriker (Trade Waste), states that the normal downward velocity of suspended matter in still water must be at least 2 millimeters per minute. He also says:

> If it be desired to perfectly clarify by deposition, on the upward continuous flow principle, water which is naturally charged with suspended matter, or by the addition of precipitants, a transverse section of more than $0.002 \times 60 = 8.33$ square meters is required to obtain 1 cubic meter per hour of clear water, in order that the upward velocity of the water may be less than the downward velocity of the particles.

The chemicals most frequently employed in water purification are alum, sulphate of iron, lime, copperas, and combinations of these. It is very important that the proportion of coagulant be always correct, else either the action is not completed or unnecessary waste results from overcharging.

COAGULANTS USED.

The series of investigations was begun by using small quantities of waste liquor—from 50 to 100 cubic centimeters—and trying the effects of various chemicals in different quantities.

ALUM.

The effect of alum was rapid, showing that it is a very satisfactory coagulant. The liquid was left slightly turbid and with some odor. The hardness was not affected. The chemical action was as follows:

$$3CaO_2H_2+Al_2(SO_4)_3+K_2SO_4+24H_2O=3CaSO_4+Al_2O_6H_6+K_2SO_4+24H_2O.$$

The quantity of alum is to the quantity of calcium oxide as 948 is to 168. About 112,000 pounds of alum is needed daily to treat waste water containing 19,800 pounds of lime and straw.

The usual process for producing alum, or sulphate of alumina, is to treat the mineral bauxite with sulphuric acid. In England some mills have found it very cheap to make the necessary quantity in their own plant. The resulting cake, according to Naylor in Trade Waste, page 21, is 36 per cent sulphate. The cost is $4.70 per short ton of product or $13.40 per ton of pure sulphate.

In the United States, on account of the excessive cost of bauxite and sulphuric acid, commercial sulphate 57 per cent pure will cost about $16 per ton delivered, or $28 per ton of pure sulphate delivered. The daily expense for 56 tons would be $1,568. This cost of partial purification, omitting other items, would absolutely prevent the operation of any mill consuming 50 tons of straw a day.

Not only is the expense objectionable, but the quantity of lime in the water, making the water permanently hard, must be reduced, else the process is not satisfactory.

SULPHATE OF IRON.

Ferrous sulphate is used in water-purifying processes, giving a dark-brown precipitate. The action is rapid and the clarification satisfactory. The use of one atom of iron for each molecule of calcium oxide present in the water produces the following reaction:

$$CaO_2H_2+FeSO_4=CaSO_4+FeO_2H_2.$$

When the proper amount of ferrous sulphate is added to 100 cubic centimeters of strawboard liquor the precipitation is almost instantaneous, and in five minutes the solid portion lies at the bottom in a brownish cake. The liquid above is very clear, having only a slight greenish tinge.

Since a daily output of 19,800 pounds of lime is assumed as a working basis, in order to make the comparison of cost apply to a particular mill 19,800 pounds of iron would be needed and 34,700 pounds of sulphuric acid.

The proper process would be to treat scrap iron with sulphuric acid in a reservoir. The expense would be—

19,800 pounds iron, at $7.50 per ton of 2,000 pounds	$75
34,700 pounds sulphuric acid (H_2SO_4), at $12 per ton	208
Cost of treatment	283

The same objections apply to the use of sulphate of iron as to alum. The expense is too great, and lime remains in the form of $CaSO_4$, which leaves the permanent hardness very high.

Instead of using sulphate of iron as above produced, the crude sulphate, copperas, a by-product of certain processes, can be employed. It is 25.9 per cent ferrous oxide and 28.7 per cent sulphur trioxide (SO_3). Roughly, 4 tons of copperas, at $9 per ton delivered, would treat 1 ton of lime. For 19,800 pounds of lime nearly 40 tons of copperas would be required, at a cost of $360 daily. While this process would be more economical than the use of sulphate of iron, when all items of expense are figured, still the cost is excessive and the process impossible as a general treatment for all the waste from a strawboard mill.

LIME.

Lime is one of the most common coagulants used in clarifying drinking waters. The usual stream carries a small amount of carbon dioxide, which combines with from 5 to 10 grains of calcium oxide to form calcium carbonate, which precipitates in fine, white particles, dragging down such organic and inorganic solids as may be held in suspension.

This process fails in treating strawboard refuse because the liquor is already many times overcharged with lime, by a part of which the little CO_2 that was in the water has been greedily used and the remaining lime is seeking more. The addition of milk of lime does not produce perceptible action.

CARBON DIOXIDE.

The facts above mentioned led at once to the conclusion that carbon dioxide must be fed to the waste liquor. On applying the computed amount of CO_2, it was found that but little precipitation actually occurred. The reason for this may be stated as follows: (1) $CaO+H_2O=CaO_2H_2$, or the lime in the waste liquor is in the form of calcium hydroxide. (2) On applying CO_2, $CaO_2H_2+CO_2=CaCO_3+H_2O$, precipitation by CO_2, occurs; but at the same time the lime is redissolved, as follows: (3) $CaCO_3+H_2O+CO_2=H_2Ca(CO_3)_2$, making a bicarbonate of lime. No precipitation has yet occurred. But if to the double carbonate of lime we add milk of lime the following action takes place: (4) $H_2Ca(CO_3)_2+CaO_2H_2=2CaCO_3+2H_2O$. Reprecipitation now takes place, carrying down the straw and calcium. The flakes are very large and the downward velocity is exceptionally rapid. In five minutes the liquor has cleared at the top and in twenty minutes the process is completed.

CARBON DIOXIDE AND MILK OF LIME.

As above indicated, it is not sufficient to apply limewater or carbon dioxide alone, but upon first saturating the liquor with CO_2 and then supplying the proper amount of milk of lime the result is very satisfactory. It will be observed that not only is the straw removed, but the water comes out soft; that is, the calcium also is removed. None of the previous treatments will precipitate the lime.

It is observed that the amount of CO_2 required for the previous reactions is two molecules per atom of calcium in the waste liquor.

From (4) it appears that the amount of calcium added as milk of lime equals the amount present in the waste liquor. Assuming that the finished strawboard does not contain more lime than is in the river water used, there are needed 19,800 pounds of lime as precipitant.

The following analyses, made by E. J. Macy under the direction of Prof. W. D. Collins, at Earlham College, will present the important facts in concrete form:

TABLE 3.—*Residue contained in strawboard waste liquor.*

[In grams per 100,000 cubic centimeters.]

	Raw liquor.	After precipitation with CO_2 and milk of lime.	
		Filtered after settling 1 hour.	Filtered after settling 24 hours.
	Grams.	*Grams.*	*Grams.*
Total residue	293.66	137.59	33.325
Combustible residue	134.63	65.63	31.250
Absolute residue	159.03	71.50	1.800

The absolute residue is a white powder, principally calcium oxide.

The above results were obtained by treating 350 cubic centimeters in a tube seven-tenths of a meter high. This form was chosen in order to approximate the depth of tank which might be employed on a larger scale. The proportions of height to cross section were not those which would be used commercially, and hence the fall of particles was hindered much more by friction against the sides of the vessel than they would have been in a larger container. After settling one hour, 53 per cent of the total solids are removed and 55 per cent of the absolute residue, principally lime. After settling twenty-four hours, 89 per cent of the total solids are removed and 98.8 per cent of the absolute residue.

EXPERIMENT STATION.

A light structure, 8 by 12 feet in plan and 14 feet high, with three stories or platforms, was erected on the grounds of Earlham College, Richmond, Ind., for the treatment of strawboard waste in larger quantities. The filters were on the lower platform and were provided with sewer connection. Above the platform was the barrel in which the precipitants were added to a given quantity of liquor. On the upper platform was the limewater and a tank for generating gas under sufficient pressure to force it against a head of 3 feet of water.

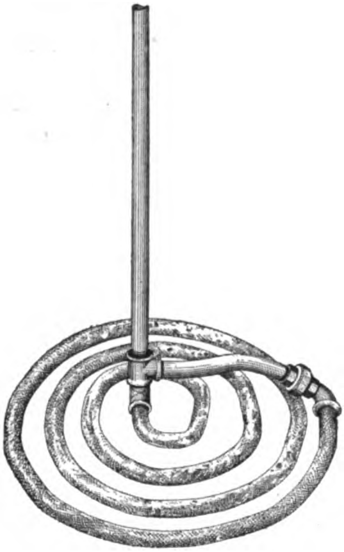


FIG. 2.—Carbon-dioxide distributor.

The gas tank consisted of a steel cylinder with a screw top closing on a gasket. A valve connection was made at the upper end and a standpipe by which to add acid. The tank was charged with a quantity of limestone. Then the proper amount of hydrochloric acid was turned down on the limestone from a reservoir within the tank. The quantity of acid was made sufficient to generate and to deliver to the waste the required amount of CO_2. A charge of 35 gallons of waste as fresh as could be obtained was saturated with CO_2, the gas being distributed through the waste by means of holes in a coil of half-inch gas pipe placed near the bottom of the tank. (See fig. 2.) The coil could be raised or lowered, and, as was expected, the best results were obtained with the gas distributor as low as possible.

The limewater was discharged through perforated pipes, shown in fig. 3, radiating from a central vertical main. The holes were arranged in such manner as to cause a swirl of the waste, which produced a very thorough mixture.

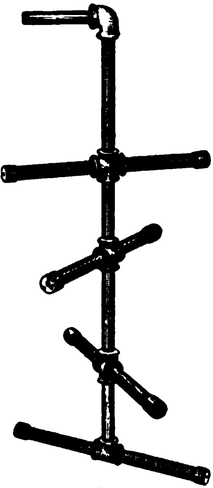


FIG. 3.—Milk-of-lime distributor.

The order of procedure was, first, to measure a certain amount of waste in the calibrated precipitation tank; second, to charge the gas generator, which delivered the proper amount of CO_2 in about ten minutes, and to apply the limewater—about 5 gallons. The resulting action was immediate. A heavy cloud of large particles formed and began a descent which indicated a specific gravity much larger than unity. The surface began to clear at once, and after settling from five to thirty minutes the process of siphoning the clarified liquor onto the filter below was begun.

The filters consisted of barrels filled with varying quantities of coarse gravel, fine gravel, and sand. These were operated at different rates, and the efficiencies were determined from analyses. Samples of the effluent and of the filtrate were taken from each barrel, and the results are recorded in table 4 (p. 27). These samples were taken when about one-half of the barrel had been treated. Five gallons of sludge were left in the bottom of the precipitation tank. This was a thick, sirup-like mass of dark-yellow straw, slightly whitened by the excess of lime that was sometimes present when a surplus of milk of lime was used.

Two molecules of carbon dioxide are required for each molecule of lime present. The strawboard company reported that 2,000,000 gallons of water were used to carry away the 19,800 pounds of lime wasted. This is equivalent to 66 grains per gallon, or about 100 parts per 100,000. The quantity of CO_2 needed was, presumably, 200 parts per 100,000 of waste.

An amount of lime should be added equal to that present in the waste, or the total lime thrown down should be about 200 parts per 100,000. As shown in table 3 (p. 23), the absolute residue in one sample of untreated strawboard waste, taken at random, was 159.13 parts per 100,000, showing an increase of 50 per cent in the proportion of lime. There is some variation in the quantity of lime used, depending on the quality of the straw, and a still greater range in the volume of water wasted.

A standard treatment was decided upon, in which the proportions were 200 parts of CO_2 and 5 gallons of limewater (or about 150 parts of lime) to 100,000 parts of waste. The color of the solid matter thrown down showed that the precipitants were sometimes used in excess.

DESCRIPTION OF EXPERIMENTS.

SINGLE BARREL TESTS.

Tests were first made by single barrels, in the manner and with the results shown below:

Barrel No. 1.

Thirty gallons of waste.

Carbon dioxide equal to 200 parts per 100,000.

Five gallons of limewater.

Stirred and allowed to settle thirty-five minutes.

Siphoned 30 gallons off in thirty minutes onto filter composed as follows: A barrel with 9 inches of very coarse gravel in the bottom; then 5 inches of gravel from one-fourth to 1 inch in diameter; next, 10 inches of coarse sand, and finally, on top, 7 inches of fine washed sand.

The area of the surface of the filter was 4.50 square feet, or about one nine thousand six hundred and eightieth part of an acre.

The rate of filtration was about 13,000,000 gallons per acre daily, which was, of course, too fast to accomplish much. Both filtrate and effluent were colored, strong in taste, and smelled of lime. No samples were taken.

Barrel No. 2.

Thirty-five gallons of strawboard waste.

Carbon dioxide.

Five gallons of limewater (milky).

Settled twenty minutes.

Siphoned 30 gallons onto filter in 1 hour and 52 minutes.

The precipitated matter, 4 inches deep, was light yellow. Free lime present. Sample after precipitation 50 per cent cleaner.

The effluent was still clearer, with bitter taste and some odor, and was still yellow color.

Filtration was at the rate of about 3,500,000 gallons per acre daily, which removed about 16 per cent of the lime that came to it (see sample 2, table 4).

Barrel No. 3.

Thirty-five gallons of strawboard waste.

Carbon dioxide.

Five gallons of limewater.

Fourteen minutes to charge with gas.

Settled six minutes.

Time of filtration, two hours and twenty minutes.

Rate of filtration, 2,780,000 gallons a day.

Filter, 9 inches of coarse gravel in bottom, 2 inches of fine gravel, 16½ inches of fine washed sand on top.

The liquor from precipitation tank showed 244.18 parts per 100,000 of lime. After filtration it showed 177.68 parts. Efficiency of filter equals 27.6 per cent. Color and taste noticeable.

Barrel No. 4.

Thirty-five gallons of strawboard waste.

Carbon dioxide.

Five gallons of limewater.

Took seventeen minutes to charge with carbon dioxide.

Settled six minutes.

Time of filtration, three hours and forty-five minutes.

Rate of filtration, 1,730,000 gallons per acre daily.

Filter, 2 inches of very coarse gravel in bottom, 2 inches of gravel, then, on top, 22 inches of medium washed sand, which passed sieve of one-eighth inch mesh.

It will be noticed in sample 4, table 4, that the effluent from the precipitation tank contained only 85.12 parts of lime per 100,000, or about one-third that found in the previous cases and about 53 per cent of the absolute residue in the untreated sample of table 3. It is certain that more than 50 per cent of the absolute residue was removed by the process of precipitation. On the other hand, the filter apparently accomplished nothing. This result is probably due to lime which was carried over in the previous work and which was washed out of the filter with the present filtrate.

TABLE 4.—*Amounts of calcium, free ammonia, and albuminoid ammonia contained in effluent of strawboard treated with carbon dioxide and lime water in experiments at Earlham College, Indiana.*

[In parts per 100,000.]

	Sample No. 2.		Sample No. 3.		Sample No. 4.	
	Before filtration.	After filtration.	Before filtration.	After filtration.	Before filtration.	After filtration.
Calcium	283.024	236.868	....	....	85.12	89.78
Free ammonia	1.675	.7	.835	.8	2.50	3.0
Albuminoid ammonia	1.125	1.336	1.0	.7	1.0	1.15

TEN-BARREL TEST.

In order to approach commercial methods as closely as seemed possible in a small experimental plant, a test of 10 barrels of strawboard waste was arranged to close the work.

First. Three barrels of waste were run through the precipitation tank, filling it and two other barrels, which served as reservoirs. The milk of lime and CO_2 were fed continuously and in proportion to the rate at which the waste flowed. It was difficult to regulate the flow of the waste by valves, as the straw would choke them, thus varying the discharge. It was therefore necessary to make the rate of flow into the precipitation tank high. Automatic floats could not be used to properly proportion the waste and lime, as the volume discharged was too small to overcome the friction of such devices.

The two reservoir barrels were allowed to stand twelve hours; then samples were taken from the top of each. The first barrel was siphoned onto a coke filter, consisting of a barrel with 2 feet of fine coke breeze, the top 6 inches of which consisted of particles one-fourth inch in diameter.

The second barrel was siphoned onto a sand filter having 6 inches of fine gravel in the bottom and 24 inches of fine sand on top. The latter passed a sieve of one-eighth inch mesh.

The rate of filtration was 50 gallons in twelve hours. As the filters were approximately 0.0001 of an acre in area, the rate of filtration through the coke was 1,000,000 gallons per acre per twenty-four hours. The rate through the sand was half as rapid, or 500,000 gallons per acre daily.

Precipitation and settling in the first barrel removed 47 per cent, and in the second barrel 90 per cent, of the suspended matter. The coke filter accomplished practically nothing. The sand filter removed 25 per cent of the suspended matter reaching it, making the total removal by precipitation, twelve hours' sedimentation, and sand filtration, 92.6 per cent. The greater efficiency of the precipitation into the second barrel was due to a better adjustment of the proportions of lime and CO_2 to the waste.

Second. Two reservoir barrels were again filled in order by the effluent from the precipitation tank. Each settled one hour. Then one filtered through the coke, the other through the sand, each at the rate of 50 gallons per twelve hours, or 1,000,000 gallons per acre daily. The efficiency of the precipitation and settling one hour was 20 per cent; of precipitation, settling one hour, and sand filtration, 90 per cent.

Third. In another and similar case the efficiency of precipitation and settling thirty minutes was 75 per cent; of precipitation, settling thirty minutes, and sand filtration, at the rate of 50 gallons in six hours, or 2,000,000 gallons per acre daily, 80 per cent.

Fourth. Similarly the efficiency of precipitation and settling fifteen minutes was 80 per cent, while the addition of sand filtration at the rate of 4,000,000 gallons per acre daily removed 86 per cent of the suspended matter.

Fifth. In another case the efficiency of precipitation and settling twelve hours was 92 per cent; of precipitation and settling eighteen hours, 86 per cent.

Sixth. The precipitation tank was run continuously, and two samples taken from the top showed 47 per cent, and fifteen minutes later 60 per cent, of the suspended matter removed. The gas bubbled up throughout the entire cross section of the precipitation tank. This constant ebullition prevented the suspended matter from settling as it should and as it would in a tank described later, in which the ebullition is confined to the delivery pipe, in which the flow is downward to the bottom of the precipitation tank.

Seventh. The waste and milk of lime were delivered at the bottom of the precipitation tank, where the gas was added, at the rate of 100 gallons in twelve hours. The effluent taken from the top was delivered into the bottom of a reservoir barrel. From the top of it ran two siphons—one to the coke and one to the sand filter—each discharging at the rate of 50 gallons per twenty-four hours, or 500,000 gallons per acre daily. The precipitation removed 36 per cent of the suspended matter, and the coke filter removed 42 per cent of the remainder. At the same time the sand filter removed 66 per cent. The total efficiency with the sand filter was 79 per cent.

Eighth. The sludge drawn from the bottom of the precipitation barrel showed 9,884 parts per 100,000 of suspended matter, or 40 times that in the untreated waste.

DISCUSSION OF TESTS.

The above efficiencies are all figured on the basis of a single sample of untreated waste which contained 238.9 parts per 100,000 of suspended matter. To have taken a sample from each barrel would have increased the number of analyses by ten, and would not have effected the results materially. As it was, 21 analyses were made. Different barrels differ in the quantity of suspended matter, of total solids, and of calcium present. The quantity of lime was sometimes too great, and at other times the quantity of CO_2 may not have been sufficient. These facts account for the discrepancies that arise. The average efficiency of precipitation in removing suspended matter from 10 cases was 63 per cent. The average efficiency of precipitation, settling for various periods, and sand filtration was over 85 per cent.

TABLE 5.—*Analysis of sample of untreated waste from fourth barrel.*

[In parts per 100,000.]

Suspended matter:	
Organic residue	149.8
Inorganic residue	88.8
Total residue	238.6
Total solids:	
Organic residue	362.5
Inorganic residue	181.0
Total residue	543.5
Calcium	160.6
Nitrates	None.
Nitrites	None.
Chlorine	71.8
Ammonia, free	.74
Ammonia, albuminoid	.60

Reaction, alkaline.
Coloring, organic.

TABLE 6.—*Residue contained in suspended matter in samples 2 to 21.*

Sample.	Total residue.	Organic residue.	Inorganic residue.
No. 2	125.8	57.2	68.5
No. 3	128.7	86.5	42.1
No. 4	23.5	16.0	7.4
No. 5	17.7	11.0	6.7
No. 6	200.0	133.7	66.2
No. 7	215.0	160.3	54.6
No. 8	62.0	43.9	17.9
No. 9	24.0	14.0	9.5
No. 10	60.5	36.8	23.5
No. 11	48.0	29.3	18.6
No. 12	195.8	123.5	71.9
No. 13	33.8	24.4	9.3
No. 14	152.0	105.3	45.6
No. 15	88.8	61.0	27.6
No. 16	50.0	35.0	14.9
No. 17	126.5	75.3	51.1
No. 18	89.5	51.5	37.9
No. 19	19.0	12.5	6.4
No. 20	33.6	11.1	12.3
No. 21	9,884.0	5,361.6	4,501.5

Samples 2 and 4 were taken from the tops of the reservoir barrels. Samples 3 and 5 are of filtrates from the coke and sand filters, respectively, taken at the middle of each test. The barrel from which sample No. 2 was taken was run through the coke filter. The barrel from which sample No. 3 was taken was filtered through sand.

Reservoirs Nos. 1 and 2 were filled and permitted to settle one hour, after which samples Nos. 6 and 7 were taken from reservoirs 1 and 2, respectively. Reservoir No. 1 was then run through the coke filter and No. 2 through the sand filter at the rate of 1,000,000 gallons per acre a day. Samples 8 and 9 are from the filtrates through the coke and sand, respectively.

Reservoir No. 1 was filled and allowed to settle thirty minutes. Sample No. 10 was then taken from the top. It was siphoned onto the sand filter at the rate of 2,000,000 gallons every twenty-four hours. Sample 11 is from the filtrate.

Reservoir No. 2 was filled and allowed to settle fifteen minutes. Sample 12 was collected as the liquor was siphoned from the top of reservoir No. 2 onto the sand filter, through which it passed at the rate of 4,000,000 gallons per acre daily. Sample 13 is from the filtrate.

The precipitation tank was run continuously, discharging into reservoir No. 1. From the top of the latter siphons led to the coke and sand filter. The rate of discharge from each was 50 gallons in twelve hours, or 1,000,000 gallons per acre daily. Sample 14 was taken from the top of the reservoir. Sample 15 was from the filtrate through the coke, and 16 from the filtrate through the sand.

Sample 17 was taken from the top of the precipitation tank during its operation, and sample 18 was collected fifteen minutes later.

Sample 19 was obtained from the top of the precipitation tank after it had settled for a period of twelve hours.

Sample 20 came from the top of the precipitation barrel after it had settled eighteen hours.

Sample 21 is of sludge drawn from the bottom of the precipitation tank.

The effect on solids in solution, especially on the calcium, was not so satisfactory, owing to the lack of sensitive apparatus by which to gauge the proper proportions of milk of lime. There was either an excess or a deficiency of lime, leaving an undesirable amount in the effluent. So long as the quantity of CO_2 is sufficient to saturate the liquor no variation in it is needed, but for the most successful operation of the process the volume of lime should be automatically regulated by the rate of flow of waste.

MIXING APPARATUS.

English and American experience suggests that the waste, CO_2, and milk of lime should be brought together during a downward flow, and that the precipitation should take place during a following slow, quiet, upward movement.

The milk of lime may be proportioned to the waste by a float in the chamber leading to the waste weir. This float would vary the length of a weir of constant head which feeds the milk of lime to the waste. The mixture should then travel down a central shaft through a nest of tubes perforated on the lower side, from which CO_2 issues under about 2 feet of head. The treated waste now travels down the central shaft to the bottom of the tank, where the flow turns upward with a very low velocity. The less the upward velocity the greater the efficiency of precipitation. The effluent would be collected at the top in semicylindrical troughs.

In the tests above reported 50 gallons were run through a tank of 50 gallons capacity in one hour. The cross section of the barrel was 649 square inches, making an upward velocity of 0.005 of an inch per second. To treat 1,000,000 gallons a day with the same upward velocity would require a tank of 83,300 gallons capacity, or 25 feet square and 15 feet deep. In the tests made the CO_2 was distributed throughout the barrel, and the violent ebullition kept the precipitation from being satisfactory, unless 15 to 30 minutes be given or the effluent be run into settling reservoirs. By confining the ebullition to a central small cylinder, where the downward flow takes place, the efficiency of the precipitation would certainly be increased.

PRODUCTION OF CARBON DIOXIDE.

The most important problem in the application of this method of purifying strawboard waste is the production of the required amount of carbon dioxide in an economical and practical manner. Two methods of producing this may be considered.

First method.—Carbon dioxide may be produced by burning lime in closed kilns, such as are used in the manufacture of beet sugar. In the typical factory which we have assumed, using 50 tons of straw a day, nearly 10 tons of lime are needed in the process of manufacture, and an additional 10 tons are required for purifying the waste. A closed kiln of 20 tons daily capacity, with rock hoist and gas pump, would cost $10,000. The operation would require 4,800 pounds of coke a day and the attendance of three men on each shift. Figuring interest, depreciation, labor, and coke, the daily cost of CO_2 produced would be $31.90. Neither profit nor loss is figured on the lime. Finally, the quantity of CO_2 would be only about 25 per cent of that required. To produce 80 tons of lime a day would necessitate a correspondingly great outlay and the production of 60 tons of lime for which a market must be found. Manifestly the method does not recommend itself, especially in comparison with the following one.

Second method.—At the plant which has been cited, where 50 tons of straw are used each day, about 80 tons of Brazil (Ind.) bituminous coal are burned every twenty-four hours. This coal contains about 70 per cent carbon. Consequently, 70 per cent of 80 tons, equaling 56 tons, or 112,000 pounds, of carbon are consumed each day. About 12 pounds of air per pound of carbon are necessary for combustion. In the average hand-fired furnace an excess of 50 per cent of air is supplied, making 18 pounds of air per pound of carbon. In the above case there would be 18 times 112,000, or 2,016,000, pounds of air needed. A series of 16 tests reported shows that the per cent of CO_2 in the chimney gases ranges from 8 to 19 per cent. Assuming 10 per cent as a conservative amount, there would be 10 per cent of 2,016,000, or 201,600, pounds of CO_2 available every twenty-four hours from the flue gases. The maximum amount of carbon dioxide needed in the precipitation is twice 19,800, which equals 39,600 pounds. Only 20 per cent of the chimney gases would be needed in the process of purification. Gas pumps capable of delivering 250,000 cubic feet per twenty-four hours, under the pressure of 2 feet of water, would be required.

The cost for gas pump and installation would be $2,500, with no additional attendance above the usual engine-room staff. Figuring cost on the same basis as before, it would amount to $1.35 per diem, as compared with $31.90 in the previous case, a saving of $30.65 a day. The actual cost of producing the necessary lime and CO_2 would be the cost of 10 tons of lime at $5 per ton, or $50, plus $1.35 for pumping, making a total of $51.35 daily.

The cost of installing a precipitating tank and mixing apparatus is so dependent on local conditions that no figures can be given unless the conditions be known. In almost all cases the design could be adapted to the topography, so that it would be unnecessary to pump either the waste, the effluent, or the sludge.

While it is believed that under average conditions filters are not needed, if a higher degree of purification is required at times of very low stream flow than the normal operation of the precipitation tank provides, gravity filters could be employed. Under some conditions a second settling tank, or two precipitation tanks with a reduced rate of flow, might be the more economical. To operate a filter requires an available head of about 3 feet from the surface of the tank. To operate two tanks either in series or in parallel requires practically no additional head.

TREATMENT OF SLUDGE.

Would it pay to treat the sludge in order to recover the lime? Take, for example, the 50-ton mill which wastes 19,800 pounds of lime daily. Assuming an efficiency of 75 per cent in the purification by precipitation alone, there would be present in the sludge 75 per cent of twice 19,800, or 29,700, pounds of lime. Only about 85 per cent of this is recoverable, i. e., 26,700 pounds.

No more economical method of drying the sludge is known than that employed in the manufacture of strawboard itself. Hence the cost may be considered the same. An official of a strawboard company states that the hot rolls receive the pulp from the wet end, press it while it is about 66 per cent water, and deliver it with about 10 per cent of moisture remaining. The cost of removing this 56 per cent of water present is the principal item in the expense of drying. The company estimates that it requires 11 horsepower for twenty-four hours, or 264 horsepower hours, to dry 1 ton of board. If we take 30 pounds of steam as equivalent to 1 horsepower hour, then 11 × 24 × 30, or 7,960, pounds of steam are required per ton of product. If 7 pounds of steam be generated per pound of coal burned, 1,274 pounds of coal are consumed, which, at $3 per ton, makes the cost $1.91 per ton of product. One-half the cake is straw and one-half carbonate of lime, hence the cost per ton of lime present is $3.82.

After the sludge is dried to the consistency of strawboard it would still contain 10 per cent of moisture. To remove the remaining moisture and make the lime available as an oxide the cake must be burned in a limekiln fired with coke, in order that the calcium carbonate shall be reduced to the oxide, thus completing the cycle through which the lime has passed. The cost would be greater than that of burning limestone, because of the greater moisture present. In addition there would be a considerable quantity of the silica present in the ash of the straw. The ash is about 5 per cent of the weight of the original straw, and of this 73 per cent, according to Remsen, will be silica. The major part of the ash would be accumulated waste material unseparated from the lime. It would evidently cost more to recover the lime in the sludge than it is worth.

The particles of straw are so fine that they will not work up into even a second-grade board. In fact, no use for this material has been discovered, hence its waste. The process of manufacture is so very wasteful, then, partly because present methods can not make this finer portion into salable stock.

The question of making a separate product from the sludge was raised. This material contains lime and silica principally. Would it make boards similar to asbestos boards to serve as nonconductors to heat? Whether or not the material, pressed and bonded by cloth, would make a nonconducting article like felt has not been carefully considered.

English patent No. 16966, issued August 6, 1898, covers a process of fireproofing wood or straw by treatment with carbonate of potash, boric acid, sulphate of magnesia, and sulphate of ammonia (see Jour. Soc. Chem. Ind., August 31, 1899, p. 763). The method would not be commercially applicable in this case in view of the ruling prices of felt and asbestos. At present it seems that the only rational way to dispose of the sludge is to run it out on the ground.

CONCLUSIONS.

1. Strawboard waste is an extremely stable substance which does not degenerate when kept in clean containers, but when mixed with other substances of a putrescible nature, such as sewage and other organic matter in streams, it becomes very foul and objectionable.
2. Simple sedimentation is not effective in the purification of strawboard waste.
3. Chemical precipitation appears to be satisfactory from every standpoint except that of cost, which makes it commercially impracticable.
4. Filtration without previous sedimentation is impracticable, but combined with sedimentation is an aid to the process.

5. The sulphates of iron and alumina are the most effective chemical precipitants for the purification of strawboard waste, but so large are the amounts which it is necessary to use that the cost is prohibitive.

6. Lime is of no value as a precipitant.

7. Carbon dioxide has no effect upon the suspended matter in strawboard waste.

8. The combination of carbon dioxide and milk of lime is effective when properly applied, and the process can be economically maintained if conditions are favorable. The results of experiments indicate that 75 per cent of the suspended material can be removed by precipitation with carbon dioxide and milk of lime at high speed of treatment. Higher efficiencies can be obtained at lower speed and by the combination of sand filtration. It is believed, however, that the latter would be necessary only in extreme cases.

SUPPLEMENTARY NOTE.

The objection raised by the officials of the United Box Board and Paper Company to the purification process described in the preceding pages is based upon its cost. It is maintained that the different kinds of box board now upon the market are so evenly balanced in cost of production and competitive selling price that the additional expense incurred in manufacture, which would result from the adoption of this process, would drive strawboard from the market. Nevertheless, it is hoped that the experiments here recorded may stimulate interest in the question considered and aid in directing research that will lead to a satisfactory solution of the problem.

DISPOSAL OF OIL-WELL WASTES AT MARION, IND.

By Isaiah Bowman.

INTRODUCTION.

Since 1886, a date which marks the beginning of the oil and gas industry in eastern Indiana, there has been more or less speculation concerning the pollution of wells and streams in the oil fields in so far as such pollution impairs the purity of drinking water or damages water for domestic and industrial uses. Within the last few years the matter has assumed a more serious aspect. Considerable litigation has resulted from attempts to collect compensation for damages to surface wells by this form of contamination.

In the following pages the manner in which such pollution occurs is shown, and a remedy is suggested for the conditions. The data presented relate to the city of Marion, this city having been chosen as the place of inquiry because it is situated in the center of the oil fields of eastern Indiana and because many cases of well and stream pollution are known to exist there.

Acknowledgments are due to Mr. E. Hulley, superintendent of the Marion waterworks, and Messrs. John E. Weigel and W. L. Benson, well drillers, for assistance rendered by them in preparing this paper.

TOPOGRAPHY AND DRAINAGE OF THE REGION.

The city of Marion is located on Mississinewa River. This stream is tributary to the Wabash and has a length of about 100 miles. The general course of the stream is northwestward, and the channel lies just outside the Mississinewa moraine. Above Marion the river swings against the moraine, cutting steep bluffs into the clay; but near the Arcona bridge, between Eighteenth and Nineteenth streets, it cuts into a gravel terrace formed outside the moraine by the stream when it was overloaded by material derived from the ice which then rested against the moraine. Just opposite Marion-on-the-River, and again near the Washington Street Bridge, the Mississinewa flows over rock. This greatly impedes the dissection of the till plain and terraces in which the river valley has elsewhere been incised. The difference in the character of the material that the river must remove has resulted in alternate straight and meandering stretches. Each outcrop of rock in the channel is generally indicated by a marked sinuosity of the stream above it.

Back of the river bluffs, which have an average height of about 50 feet, the surface of the country to the southwest is extremely level, and drainage, especially on the flat and wide divides, is sluggish and ineffective. Northeast of the river the Mississinewa moraine gives some relief to the surface, although that part of the moraine near Marion has an average height of not more than 20 or 30 feet.

The valley bottom varies greatly in width. In places it is but little wider than the river, while in the vicinity of the pumping station it is from a half mile to a mile wide. The business part of the city and its more thickly settled portions lie on an old flood plain of the Mississinewa. The oil wells are scattered over the whole region, alike in valley bottom and in the country back of the river bluffs. Occasionally, where the bluffs have a gentle descent, oil wells may be found on them, as well as on the lower surfaces nearer the river, positions which have the advantage of rapid drainage, while the others have the association of stagnant pools of waste oil.

GEOLOGIC FEATURES.

PLEISTOCENE DEPOSITS.

At the place where Sixth street ascends the river bluffs in the western part of the city there is a typical 30-foot section of the till plain. Beneath a covering of till about 10 feet thick is a layer of gravel, which in turn overlies a layer of iron-stained bowlders several feet thick. Below this is a promiscuous deposit of clay and gravel, underlain by cross-bedded and fine-textured sand.

The upper covering of till is persistent throughout this region, varying in thickness from several inches to 15 feet. It is, of course, absent in the valleys where the river has undercut it. Where it is thin it is very porous, because of oxidation and the action of vegetation, so that it offers no obstruction to the free passage of percolating water. Along the present stream channel and over the older flood plain that lies between the bluffs are scattered bowlders which the river has been able to undermine and dislodge from the bowlder bed previously mentioned, but which it is not able to carry downstream. In places the till is so free from pebbles that it is used in the manufacture of brick.

A number of well sections are given herewith, since they represent the character of the glacial deposits, an understanding of which is essential to an appreciation of the conditions of water contamination. The best well section procured in the vicinity of Marion was that obtained at the pumping station of the city waterworks. At the request of the writer samples of the borings were saved by Mr. E. Hulley, superintendent of the waterworks. The well was drilled in October, 1903. In studying the section it must be remembered that the pumping station is in the valley of the Mississinewa and that the bluff section given above must be added to the well section in order to get a fair notion of the character of the deposits from the surface of the till plain to the rock.

The samples were examined both microscopically and macroscopically. A description of them follows:

Section of well at city waterworks, Marion, Ind.

	Thickness of stratum in feet.	Depth to bottom of stratum in feet.
1. Fine sand and black loam (a peaty deposit in a part of the river channel now abandoned)	3	3
2. Very fine, yellow, sharp, ferruginous sand	28	31
3. Coarse gray sand, the grains being rounded through water action	15	46
4. Fine gravel, made up mostly of erratic material and quartz sand	4	50
5. Pale reddish-brown clay with many stones and considerable gravel, also some iron concretions. The stones and pebbles were of chert, limestone, trap, shale, and quartzite. (Limestone, shale, and chert pebbles seem to have been derived from the underlying rock)	54	104
6. Gray clay, very plastic when wet and containing no pebbles. This clay is remarkably pure and is distinct from the clay bed above it in containing no pebbles whatever in its middle portion, though it merges gradually into the pebbly clay above	26	130
7. Limestone (Niagara). The limestone is water bearing from the top to the last depth given and presumably beyond, but the best supply comes from a subporous and greatly fissured layer 38 feet below the rock surface	58	188

This is a flowing well, the water rising (when the well is piped up) to a height of 18 feet above the surface.

The following boring records were kindly furnished by Mr. John E. Weigel, of Marion, Ind. They show the character and depth of the material overlying the rock at the various places indicated by the corresponding numbers on the accompanying map (fig. 4).

Material overlying rock at certain localities indicated by numbers on fig. 4.

	Feet.
1. Sand and gravel	0–30
2. Sand and gravel	0–17
3. Sand and gravel	0–37
"Blue" clay	37–45
4. Sand and gravel	0–57
"Blue" clay	57–65

		Feet.
5.	Gravel	0–50
	Mixture of gravel, sand, and clay	50–105
6.	Gravel and sand	0–50
	Till as in No. 5	50–60
7.	Rock in river bottom	0
8.	Till, sand, and gravel	0–100
9.	Sand and gravel	0–32
10.	Sand and gravel	0–60
11.	Gravel	0–40
	Till	40–100
12.	Till, sand, and gravel	0–200
13.	Till, sand, and gravel	0–200
14.	Gravel	0–50
	Till	50–105
15.	Sand and gravel	0–60
	Till	60–198
16.	Quicksand	0–55
	Till (mostly gravel and some brown clay)	55–200
17.	Gravel, bearing salt water	0–40
	Till	40–177
18 and 19.	(The samples previously referred to are from these two wells.)	

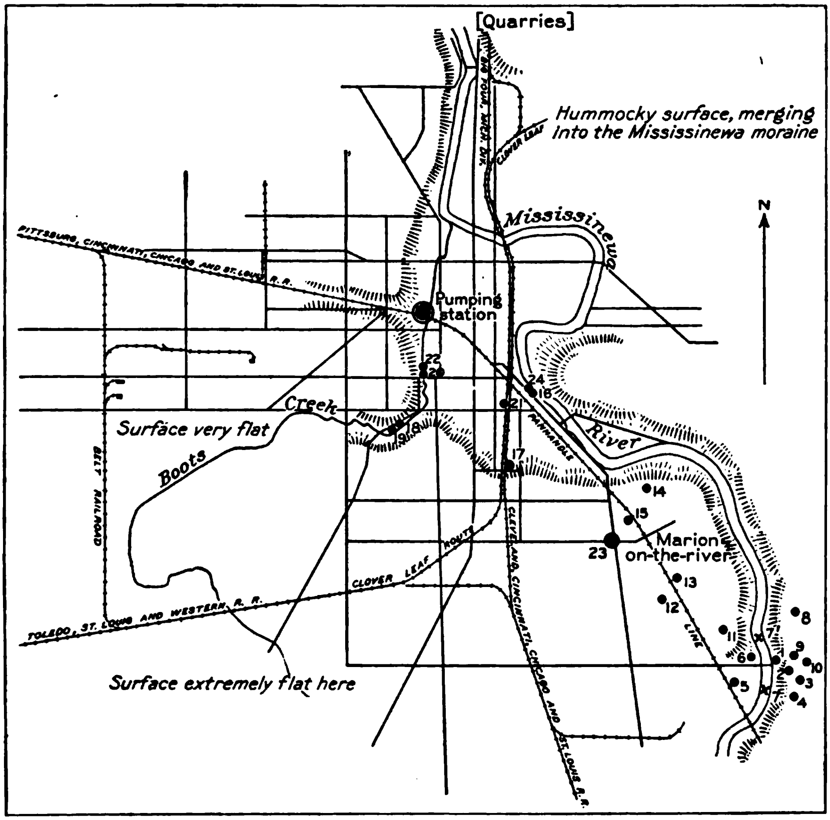

[Quarries]
Hummocky surface, merging into the Mississinewa moraine
CLOVER LEAF
BIG FOUR, MICH. DIV.
N
Mississinewa
PITTSBURG, CINCINNATI, CHICAGO AND ST. LOUIS R. R.
Pumping station
22
20
24
16
21
Creek
Surface very flat
Boots
19
18
PANHANDLE
River
17
14
15
BELT RAILROAD
Marion on-the-river
23
13
12
LINE
CLOVER LEAF ROUTE
TOLEDO, ST. LOUIS AND WESTERN R. R.
CLEVELAND, CINCINNATI, CHICAGO AND ST. LOUIS R. R.
8
11
7
6
9
1
10
2
3
5
4
Surface extremely flat here

FIG. 4.—Map of Marion, Ind.

		Feet.
20.	Sand and gravel	0–40
	Till	40–50
	Gravel	50–70
	Clay	70–169
	(This well was drilled 118 feet into limestone, making a total depth of 287 feet, but no water was encountered, and the well was abandoned.)	
21.	Sand and gravel	0–60
	Till	60–117
	Gravel	117–127
	Clay	127–216

While the last clay bed is extensive, it by no means covers the entire surface of the rock, for well sections frequently show glacial gravel and till all the way to rock. No bowlders are known to occur in it, and the deposit may be nonglacial. Gravel is said to underlie it in places, but none of the gravel was obtainable, and its nature is therefore uncertain.

In the foregoing records no distinction was made between this clay bed and the pronouncedly glacial material overlying it, although an examination of the samples showed that such a distinction exists.

The well sections show that there is an extensive area of rock surface not covered with clay, the entire section yielding only sand and gravel. It also appears that the upper layers of clay, or more properly, of till, and the layers of gravel are in many places differentiated, while in others there is a more or less intimate mixture of these two materials. Such a mixture must not be regarded as impervious to water. There is undoubtedly a more or less free circulation of subsurface water throughout this entire mass of glacial material. This conclusion is warranted not only by a determination of the frequent high porosity of the till and its consequent permeability to water, but also by underground observations on percolating water. In assisting Mr. A. C. Veatch, of this Survey, in work done on Long Island, New York, during the summer of 1903, the writer had occasion, through the kindness of Mr. J. C. Meem, consulting engineer for the Borough Construction Company, to examine a sewer tunnel in course of construction between Sixty-fifth street and Fort Hamilton avenue, South Brooklyn. Different working faces were closely examined, and it was found that even in those places where the till was most clayey in composition the water at a depth of 90 feet from the surface had occupied the pores of the till in such manner and to such a degree that constant pumping was necessary to keep this part of the tunnel dry enough to permit work. The sand and gravel distributed through the till was sufficiently abundant to allow a constant flow of underground water. This fact must be regarded as important, inasmuch as a number of apparently anomalous cases of contamination no doubt depend for their explanation upon this quality of the till.

HARD ROCK FORMATIONS.

The hard rock formations with which this report is concerned are the Niagara limestone, the shales and limestones formerly known as the Hudson River limestone and Utica shale, and the upper Trenton limestone.

NIAGARA LIMESTONE.

Into the Niagara limestone pre-Glacial streams cut valleys several hundred feet deep. This depth was so great that the ice sheet was just able to cover the valleys and divides evenly with drift, and so enable the post-Glacial streams to take an initial course independent of the old rock valleys. The depths to rock at various places in Marion and in the region east of that city indicate that the pre-Glacial drainage was along a northeast-southwest line, almost at right angles to the general direction of the course now taken by the Mississinewa. In some of the deeper parts of this old valley the limestone has been completely eroded and the shale beneath uncovered, while over a considerable area near the bottom of the valley the limestone is but a few feet thick. Toward the divides it becomes thicker, reaching a maximum thickness of about 350 feet at the quarries indicated on the map.

The upper layers of limestone are weathered to a depth of 6 or 8 feet, the result being the formation of a dirty yellow and partially oxidized clay. In most places this clay is porous, usually covering the rock to an insignificant depth. Most of this clay was removed during the advance of the ice. It occurs at the present time only in patches, which furnish all the evidence that is available concerning pre-Glacial conditions.

The limestone lies in nearly horizontal layers. It is extensively fissured, the breaks being more numerous near the top of the section, presumably from pre-Glacial weathering, the weight of the once overlying ice, and the extremes of temperature to which the rock was subjected and the water which it contained. This condition of the limestone permits surface water to have easy access to the rock for some depth, and rock wells and springs (the latter where the rock outcrops in a favorable way) are therefore to be expected. Such springs exist in all the quarries, and the chief source of the city water supply is from wells drilled into the upper limestone rock.

It is maintained by the writer that the water occurring in the upper limestone rock is not derived from some far distant source and transmitted through possible porous layers of limestone, but is essentially of local derivation and is supplied from rainfall percolating through the glacial deposits above. This conclusion is supported by the following considerations:

1. Water must enter the limestone where it is not covered with clay.

2. Once in rock which is fissured and to a slight extent porous, the water must ultimately occupy even those parts of the rock that are covered with clay.

3. The greatest supply of water is found near the top, where the limestone is most highly fissured and where, therefore, the transmission of pressure is most quickly accomplished.

4. The deep valleying which the limestone has suffered and the consequent relation of the superimposed clay beds to the shale and the eroded edges of the limestone prevent the wide distribution of percolating water through possible porous limestone layers.

5. The rock is unevenly fissured. If there is any connection between the fissured condition and the supply from above, we should expect the greatest supply where the rock is most highly fissured; also a considerable disparity in the depths of wells, even though such wells are within short distances of one another. Many examples of the latter condition are found among rock wells.

6. The rock being unevenly fissured and of different degrees of porosity, a combination of unfavorable conditions may result and no water may be procurable from the rock in some places. Such conditions have been known to occur, although the number of cases is rare. One of the most notable occurred in November, 1903, when a boring was made for water by the city waterworks company. On the map the well is indicated by the number 22. The following material was encountered:

Section of dry boring at Marion, Ind.

	Feet.
(1) Sand and gravel	0–50
(2) Mixed gravel and clay	50–169
(3) Limestone (Niagara)	169–287

NOTE.—No water was obtained and the hole was abandoned.

7. So far as the writer has been able to determine, there are no successful wells in the limestone at any depth where the limestone comes very near to the surface, while in the valleys the wells in the rock are scarcely ever unsuccessful and they nearly always flow.

HUDSON RIVER LIMESTONE AND UTICA SHALE.

This group occurs about 365 feet below the surface and is about 560 feet thick, the Trenton limestone beginning at about 925 feet. The shales are somewhat calcareous, and near the top and bottom of the series there are frequent intercalations of bluish thin-bedded limestones. The formation is not water bearing except near the bottom, where water, saline in quality, sometimes occurs.

TRENTON LIMESTONE.

This limestone is dull gray in color, except where it is most calcitic, and there it is nearly white. Oil occurs near the top of the formation, where the rock is extremely porous. Beneath the oil is salt water, which is pumped out with the crude oil in large quantities. If pumping is continued irregularly the oil well may be permanently injured by the inflow of salt water. In the earlier days of oil wells the driller frequently drilled to too great a depth and the inflow of brine was so strong that the well became useless. In order to form a reservoir for the collection of oil the limestone must be entered some distance, and the most successful wells are those which are drilled deep enough to allow a large amount of oil to collect and still be some distance above the upper level of the brine. The oil wells are usually about 1,050 feet deep, the oil rising to within 600 or 700 feet of the surface.

SOURCES OF CONTAMINATION.

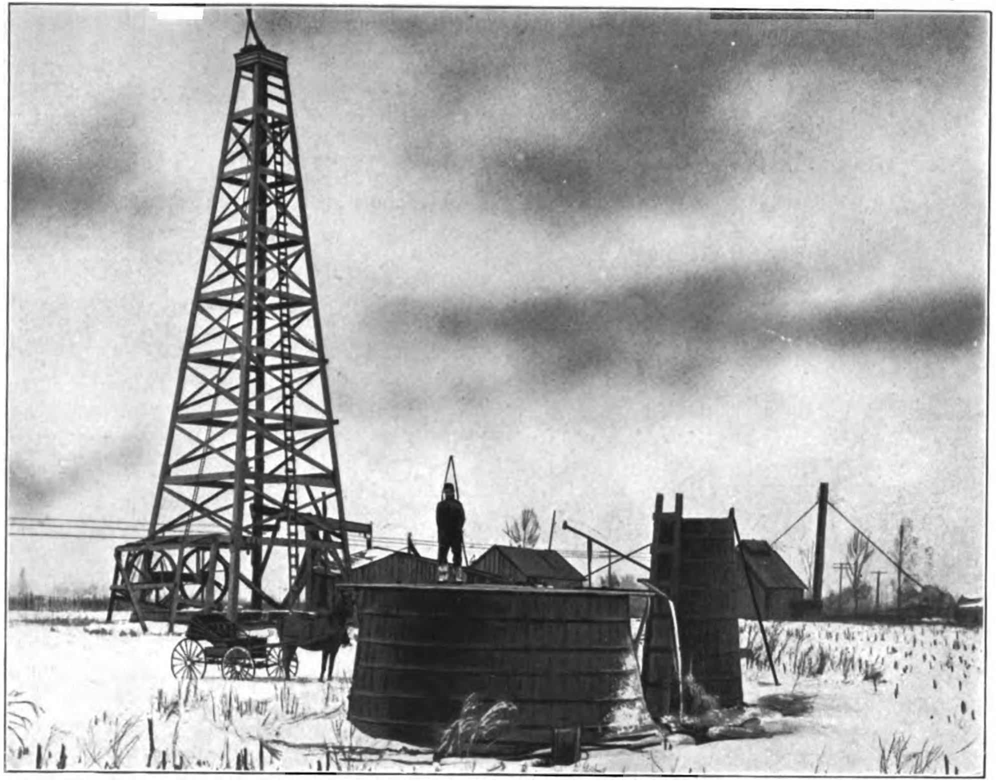
Scarcely a week passes but the boring of an oil well near Marion is completed and the well is "shot" with nitroglycerine. The shooting, no doubt, breaks up the porous Trenton limestone and forms fissures and small caverns, which act as reservoirs into which the oil will flow if this substance occupies the pores of the rock at that place. The surface effect of the shooting is the violent ejection of salt water and oil, often to the estimated amount of thousands of gallons. The oil and salt water sink into the soil, where it is sufficiently porous, and finally reach the surface zone of underground flow, where they partake of the general movement of the water toward the main line of underground drainage.

Wells reaching this saturated zone and lying between the oil well and this line of drainage, or thalweg, become polluted. This takes place even though the amount of oil contributed during a week or a month should be small; for the oil, being lighter than the water and having greater viscosity, is subject to less favorable conditions of lateral flow, and the ratio of the amount of it in the well to the height of the vertical water column of which it forms a part tends to be greater than the ratio expressing a normal condition elsewhere in the saturated zone.

By a similar process of reasoning we are led to believe that the brine, but not the oil, should pollute wells which derive water from deeper zones of flow or from the bottom of the surface zone. This will be true especially where depressions occur in the clay of the drift, or along the main line of underground drainage. This conclusion seems to be supported, in part at least, by the records given elsewhere in this paper, its final justification depending on its accordance with a larger amount of data. The slope of the ground being usually indicative of the direction of flow of underground water, an examination of the surface slopes with reference to a near-by water well should indicate whether or not pollution may arise in a given locality through the circumstances attending the sinking and working of an oil well. In sinking water wells, depressions in the drift should be avoided, as well as the deeper parts of the valley. As will appear more clearly later in this discussion, however, the burden of responsibility for contamination rests not on the owners of water wells but on the owners of oil wells, for the latter are usually in the field later than the former and locate their wells often with no regard to the rights of others and in contempt of well-established theories of contamination.

If the contamination of wells were due alone to the oil and salt water which is thrown out at the shooting of a well the number of cases of pollution might be much smaller than it is now, for a great deal of the liquid thrown out runs off quickly into the creeks, and only a part of it, except where the surface is level or the ground porous, sinks into the soil. There is another and more prolific source of contamination. The brine and oil pumped from an oil well are delivered to a tank having a capacity of 100 barrels or more. Near the bottom of the tank a pipe leads up at an angle with the side, and it is through this pipe that the salt water is allowed to escape. (See Pl. IV.) A little below the level of the top of the liquid in the tank another pipe leads off. It is through this one that the oil is conducted. The adjustment of these two pipes is made with reference to the capacity of the well, so that but little waste of oil occurs from this source. Some, however, does find its way out of the pipe intended to convey only salt water, and this oil, together with that which is derived from various leaks in the tank and from pumping, result in a constant flow of brine and oil from the well and tank. In many cases the owners of these wells pay no attention to the disposition of this refuse, but allow it to lie in pools or to run slowly over the adjoining fields. Some of it finds its way into the creeks and so into the river, while still another part sinks slowly into the ground. In some cases the attention of owners has been called to the danger of pollution, but only a few of them take the precaution to construct a ditch from the well to the nearest ravine or creek.

It is instructive in this connection to note the manner in which pipes are inserted into the bore holes in rock and the danger of pollution resulting from this method. An 8-inch pipe, called a drivepipe, is driven down through the various materials above the rock as rapidly as the material at the bottom of the pipe can be removed by means of a sand bucket, and is then forced into the upper limestone to a distance of from 5 to 15 feet. With the largest drill that will work in the casing the hole is continued down through the upper limestone as far as the shale overlying the Trenton limestone. Here the size of the bit is reduced, and, after the hole is drilled some distance into the shale, the hole is cased with a 5⅝-inch pipe. The shale itself contains no water, except very small amounts near its base, but the limestone overlying



RECEIVING TANK WITH DISCHARGE PIPES.

it is saturated. It is the effort of the driller to so tightly fit the casing into the shale that no water from the overlying limestone can follow down the pipe to its open lower end. Such a passage along the pipe would either allow the oil to escape upward, or the surficial waters, with sand, clay, etc., to pass downward into the oil, according to the direction of circulation.

The space between the casing and the sides of the hole in the limestone permits such oil and brine as have passed downward through the soil to have easy access to the waters in the limestone. This takes place oftenest where the limestone is near the surface and where the material above it consists wholly of sand and gravel. The water in this loose material will tend to move nearly vertically downward, but contamination will occur with almost equal certainty where the direction of movement has a strong horizontal component, the wells being so numerous and crowded that the refuse from one readily contaminates the water in the rock adjacent to others. In the vicinity of the Thirty-eighth Street Bridge the water table stands from 30 to 35 feet below the surface, showing that the movement of whatever additions it may be receiving by downward percolation from the surface must be nearly vertical, as evidences of lateral movement, as expressed by any rise of the water table, are absent. The water level in the rock at this and similar places seems to supply additional proof of the local sources of the water. The flowing wells in the valley are at least 50 or 60 feet lower than those about Thirty-eighth Street Bridge, and the height to which the water will rise in the strongest of the flowing wells seems to be always somewhat less than the height of the water level in adjacent areas. Precise levels run to the various wells would furnish data of great value in settling questionable points of this nature.

Where artesian effect is pronounced pollution from the source under consideration may not be accomplished as readily, though it seems that in time the inflow of salt water near the head would contaminate most of the water in the rock. The likelihood of such an occurrence is being strengthened continually because of the constantly increasing number of oil wells. The water from many rock wells shows at the present time an extremely high percentage of chlorine, and it is quite possible that it is now derived from that source, though, because of the relatively small amount delivered, diffusion does not allow the result to be so noticeable as it may in time become when the supply is increased.

It has been shown before that a differentiation of the refuse from an oil well may be expected to take place, the oil remaining undiffused and comparatively near the surface, while the salt water sinks down until diffusion destroys the disparity existing between the specific gravities of the brine and the water derived from rainfall. There is, therefore, more danger arising from the complete contamination of wells near the surface by means of oil than in the case of deeper wells from brine. This is true especially where the water table is lowered through excessive pumping. Any oil near the surface will be induced to assume lower and lower levels until, as pumping increases, it is drawn into the pipe. The example of this occurrence quoted below is all the more interesting when it is known that the above deduction was reached before examples of this sort of thing were known.

"On December 1," writes Mr. Hulley, "the water wells [24 on the map] of the Indiana Brewing Association, at Marion, began pumping oil. They are 160 feet deep and in gravel. They are flowing wells, but the flow not being sufficient, pumping by means of air lift is resorted to. When the amount of oil in the water becomes too great the pumps are stopped, and after standing for some time, so that the wells begin to flow, oil ceases to occur in the water. When pumping is resumed no oil is noticeable until the water level is lowered considerably through pumping." Mr. Hulley says further that the oil is without odor, showing that it has been purified by passing through sand and gravel and that it has evidently gotten into the ground from some distant source, as there are no oil wells near by.

There are thus seen to be two chief sources of danger of contamination. Oil and brine may escape between the casing and the shale and, rising to the porous or fissured layers of limestone, may contaminate the water therein, or they may sink down through the soil from stagnant pools of refuse at the surface. The danger arising from the former source seems to be very small, for, considering the height to which the oil will naturally rise and the fact that the oil wells are frequently not pumped for a day or two, the return of the oil from the outside of the casing into the well would be accompanied by an inflow of sand which would be destructive to the well. This is probably but seldom the case. Where wells have been sand choked it has not as yet been definitely proved whether the source of the sand was from above or below, the difficulty being that in both cases it would be derived from limestone. Until this danger has been proved to be actual no regulation by law will or should be attempted.

Regarding the latter source of danger, from water seeping through the soil from above, there is pretty conclusive proof. Moreover, the evil effects of the condition are so widespread and the remedy is so simple that the disposition of oil refuse should be made a subject of legislative enactment. In the country districts there is little need for vigilance beyond securing the quick removal of oil refuse to the nearest stream by means of ditches and the intelligent selection, with reference to the probable movement of the underground water, of sites for oil wells. It is in the thickly settled parts of the State, in villages and cities where water wells are more numerous, and where they can not always be properly located, that the need for a remedy is most urgent. The oil wells are, as a rule, yielding a lavish return to their owners, and there is no reason why these owners should not be compelled within proper limits to join in the construction of sewers which will convey oil refuse to the river.

The streams in this region are all more or less polluted, the water having an exceedingly unpleasant odor and a yellowish-white color. This is the color of the brine as it is pumped from the wells and is due to the presence of sulphur. From time to time public interest is aroused by the unsightly condition of the streams and there is much discussion in regard to the disposition of the water. In Marion the discussion centers about Boots Creek, for it is this creek which runs through the city and is thought to endanger health. At the present time there is under consideration the building of an aqueduct for the transportation of this water to the Mississinewa.

Regarding the healthfulness of these streams, it is noteworthy that before the beginning of the oil and gas industry they were so sluggish that in the dry season, when they were a mere succession of pools, the stagnant condition of the water, aided by the addition of sewage and foul vegetable matter, resulted frequently in typhoid fever, while at the present time, owing to the steady contributions from oil and gas wells, there is active circulation of water throughout the entire year.

Dr. W. A. Fankboner, of Marion, has this to say about the condition of Boots Creek: "Its condition now is more healthful than before oil refuse was turned into it. To be sure, to some people the odor is unpleasant, but the stream is not overgrown with weeds and covered with slime, as it formerly was at certain times of the year; and the oil has made it unpleasant as a breeding place for mosquitoes." He also says that there is no ground for the charge that more cases of typhoid fever have occurred along this creek than along other creeks but slightly polluted.

The consideration of all the foregoing possibilities, together with the fact that the city of Marion depends for its water supply upon rock wells (the surface wells not supplying an adequate amount), makes the danger seem very grave.

There are at least 75 oil wells in a few square miles of territory near Thirty-eighth Street Bridge, where clay does not overlie the rock. The amount of oil refuse that finds its way into the limestone is enormous, 200 or 300 surface and rock wells in this area, according to Mr. Weigel, suffering contamination, and unless this refuse is drained off into the river and not allowed to sink into the soil the gravest fears may be entertained for the continued purity of the city of Marion's water supply. A number of these wells were visited and the water examined. Among them were those belonging to Doctor Snodgrass and Messrs. Vansky and Keene. The location of these three wells is indicated on the map by the number 23 (p. 39). In other places, where clay overlies the rock to some thickness, the present danger may not be so great, although ultimately, because of the nature of the source from which all the water in the upper limestone is derived, the water will become contaminated even at these places.

With reference to this point, it has too long been the custom to make light of a situation that in a year or so may become very grave. Deeper sources of good water are unknown in this part of the State. The shale beneath the Niagara limestone yields practically no water, the little it does yield being saline, while still deeper is the Trenton limestone, full of oil and brine. Neither can the water from the streams be utilized, the constant inflow of brine and oil from adjacent oil wells rendering this plan impossible. Here practically the single source of the water supply of 27,000 people is threatened, and yet no adequate interest is aroused and no means are taken to prevent the danger.

The plea has been made that it is a necessary evil. The recent epidemic of typhoid fever at Butler, Pa., was due to just as "necessary" an evil, but that outbreak not only made the so-called necessity appear diminutive but made the neglect of such conditions seem criminal. It is not inferred that the same disease will follow the contamination of water through oil and brine, but it is inferred and emphasized that the discomfort and expense attending such contamination and the consequent lack of pure water may result in evils quite as great.

It is not sufficient to begin a study of remedies after mischief has been done. If even the probability of pollution of city water is proved, prompt means should be taken to prevent such pollution.

SUPPLEMENTARY NOTE.

By Marshall Ora Leighton.

To carry oil-well wastes as directly as possible into running streams of water in accordance with the plan recommended in the preceding pages for the relief of ground-water supplies from pollution by oil and brine involves the direct pollution of the streams to an extent even greater than they are now contaminated in the oil fields. The question immediately presented is whether it is better from an economic standpoint to preserve local ground waters at the expense of surface waters which in flowing downstream affect wide areas, or to conserve the interests of many riparian owners below and, so far as may be possible, to retain these wastes in the immediate localities from which they are derived. It may be argued that any locality in which oil wells are developed has, by reason of that development, such extraordinary ecomonic advantages that it may well afford to suffer for any incidental loss which may arise from waste oil and brine. And is not the pecuniary advantage which follows the discovery of oil entirely compensatory for the loss of water resources? On the other hand, if the polluting matter is turned into the streams it destroys the value of water to lower riparian owners, who at common law have a right to that water in its purest natural state. The result of such procedure would be to relieve the fortunate oil region from an unfavorable feature which it is amply able to bear—in other words, to enable it further to enrich itself at the expense of districts that are unaided by the presence of oil deposits. Yet with reference to the other side of the question, it may be said that if all possible precautions were taken to hold oil and brine waters within the oil regions there would still be a pollution of rivers nearly if not quite as complete as would arise from carrying out the plan suggested by Mr. Bowman. There is no doubt that where oil deposits are developed stream pollution is inevitable. The rain which falls upon the earth will carry with it oil and brine which it encounters on the earth's surface. In addition to this, the percolating water will reach the lowest level, and whether this water be rain or oil and brine the streams will still be polluted.

On the other hand, the people living in the oil regions must have sweet water for domestic purposes. This is a necessity which transcends all other economic demands. As shown in Mr. Bowman's discussion, the rivers in the Marion region are already unavailable as sources of pure water supply, and the only supply remaining is ground water. Therefore, as we can not save the stream and can save the ground water, there appears to be no question concerning the wisdom of accomplishing the latter end. Stream pollution in this case, as in certain others, is a part of the price paid for the accumulation of natural wealth. It can be considered an inevitable loss with equanimity, as it is only a temporary loss. Oil fields in time become exhausted and in due season the rivers will regain their pure condition. It would require an incomparably longer time to redeem an oil and brine besodden earth.

All things considered, the recommendations set forth in the foregoing paper seem to be the wisest and most expedient that present themselves at the present time.

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Author.

Sackett, Robert Lemuel.

. . . The disposal of strawboard and oil-well wastes, by Robert Lemuel Sackett and Isaiah Bowman. Washington, Gov't print. off., 1905.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

UNDERGROUND WATERS
OF
EASTERN UNITED STATES

MYRON L. FULLER
GEOLOGIST IN CHARGE

WASHINGTON
GOVERNMENT PRINTING OFFICE
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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Hydrographic Branch,
Washington, D. C., May 11, 1904.

Sir: I have the honor to transmit herewith a manuscript entitled "Underground Waters in Eastern United States," which I would recommend to be published in the series of Water Supply and Irrigation Papers.

The aim of the paper is to present a brief summary of the underground water conditions in the States east of the Mississippi and in those States bordering that river on the west. It is prepared to meet the demand of drillers and others for general information relating to the broader features of the occurrence of underground waters in the various States or districts.

The report includes papers by twenty geologists and embraces discussions of the conditions in each State and of the general occurrence of underground waters as a whole.

Very respectfully,
F. H. Newell,
Chief Engineer.

Hon. Charles D. Walcott,
Director United States Geological Survey.

UNDERGROUND WATERS OF EASTERN UNITED STATES.

M. L. Fuller,
Geologist in charge.

INTRODUCTION.

By M. L. Fuller.

The present paper is a brief summary of the underground water conditions in eastern United States, prepared to meet the demands of drillers and others for information relating to the general water resources of the various States or of specified regions.

The detail with which the several regions or subjects are discussed depends mainly on their relative importance, although because of the greater amount of work done in certain localities, or on certain problems, it is possible to make more complete and definite statements in regard to the underground water supplies in some regions than in others. The included reports have been prepared by a number of geologists, each, in general, having charge of the investigations in a particular State or group of States. Because of the number of contributors there is necessarily considerable variation in the manner of treatment of the subject, but in most cases the same general plan has been followed.

In preparing the paper simplicity of treatment has been kept in mind, and elaborate geologic discussions have been omitted. Wherever possible maps have been given in preference to long and possibly obscure discussions. In some instances, however, it has been necessary to describe the various water-bearing formations under their geologic names. Where this has been necessary the aim has been to employ those terms which are oldest and best known to the people of the States to which the discussion relates.

For the purpose of presenting in a simple manner a few of the more important features relating to the nature and occurrence of subterranean waters and of making more intelligible the descriptions of the conditions in the various States, there is given a short paper on the general occurrence of underground waters.

OCCURRENCE OF UNDERGROUND WATERS.

By M. L. Fuller.

SOURCES OF GROUND WATER.

In general those who have written on underground waters have stated that rainfall is the only source of underground waters. In reality, however, while rainfall probably contributes at least 99 per cent to the total subterranean water, there are several other possible sources of such water.

It is a well-known fact that in coral and other islands of porous material, such as sand and gravel, especially where the rainfall is light, the sea water penetrates through the pores of the rock for a considerable distance inland. Where the rainfall is heavy the salt water may be displaced to some depth by fresh water, but the downward penetration of the fresh water must be necessarily limited. In other instances sea water is known to penetrate along solution passages or caverns into the interior of limestones, and at Cephalonia, in Greece, a stream of salt water leaves the sea and, passing inland, finally disappears into porous limestones.

By far the larger portion of the sedimentary deposits, including sandstones, shales, limestones, etc., were originally laid down along the borders or beneath the surface of the ocean and were, of course, originally saturated with salt water. It is probable that this water was often retained in the materials when they became consolidated into rocks, and is represented by the salt water now found at great depths in many of the wells drilled for oil and gas, in which it is not uncommon to encounter, after passing through many hundred feet of entirely dry rock, porous beds filled with salt water, possibly accompanied by gas and oil. It is claimed by others, however, that the salt waters are not originally included portions of the sea, but are surface waters which have become charged with mineral matter which they have dissolved in the course of their passage through the rock.

Practically all volcanic rocks contain water when they are erupted at the surface and all eruptions are accompanied by discharges of large amounts of steam. The occurrence of this water has been accounted for in several ways. It may have been originally included in the rocks which were melted to form the lava, or it may represent water which has penetrated downward through fissures and come in contact with the molten lava on its way to the surface.

AMOUNT OF RAINFALL.

The rainfall in the eastern United States is abundant, and although only a portion of it is absorbed by the earth and becomes a part of the subterranean stores, the amount is sufficient to furnish ample underground supplies for a large proportion of the inhabitants. The average rainfall varies from 20 to nearly 70 inches, the lowest being in the extreme northwestern portion of Minnesota. Rain to a depth of over 60 inches a year falls on the Mississippi delta below New Orleans and along the Gulf coast from near Mobile, Ala., to Tallahassee, Fla.

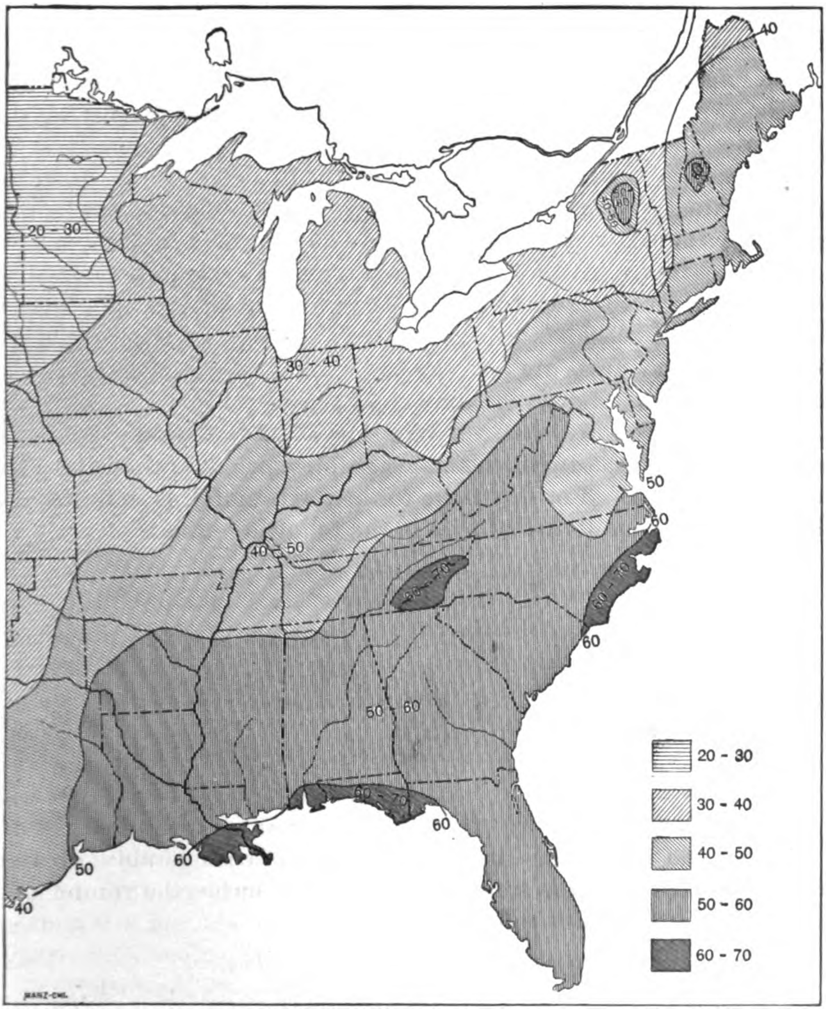

FIG. 1.—Rainfall map of eastern United States. Figures represent inches of annual rainfall.

Similar amounts fall in the higher mountains of western North Carolina and eastern Tennessee, along the coast of North Carolina, and in the Adirondack and White mountains. In the Gulf and South Atlantic States the rainfall is between 50 and 60 inches; in the New England, Central Atlantic, and Ohio River States, between 40 and 50 inches; in the Upper Mississippi and Great Lakes States, from 30 to 40 inches, while in northwestern Iowa and most of Minnesota the rainfall is only from 20 to 30 inches.

DISPOSAL OF RAINFALL.

The rainfall is removed from the surface principally in three ways: (1) By evaporation; (2) by run-off through the streams, and (3) by absorption into rocks and unconsolidated deposits.

Evaporation.—Evaporation, although far less conspicuous than the other methods of removal of the water, is, nevertheless, one of the most important. The amount evaporated depends on the temperature and the relative dryness of the air, and commonly amounts to one-half or more of the total water falling as rain. Locally, evaporation is dependent to a considerable extent on the density of the vegetation, but when broad areas are considered the amount of vegetation has a less conspicuous effect on the total evaporation.

Run-off.—The amount of run-off is dependent partly on evaporation and partly on the nature of the materials on which the rain falls. The proportion of run-off or discharge to the total rainfall is indicated for the Mississippi and its tributaries in the following table:[a]

Proportion of run-off to rainfall in Mississippi basin.

	Per cent.
Ohio	24
Missouri	15
Upper Mississippi	24
Small tributaries	15
Arkansas and White	15
Red	20
Yazoo	90
St. Francis	90
Entire Mississippi system	25

The run-off of streams in New England is considerably greater. With a rainfall which averages from 40 to 50 inches the run-off of a number of streams is as follows:

Proportion of rainfall to run-off in New England.

	Inches.
Kennebec	22.4
Androscoggin	24.2
Merrimac	21.3

Absorption.—The rainfall that is not removed by evaporation or by the surface streams is absorbed by the soil or rocks with which it comes into contact, either directly or after being gathered into streams.

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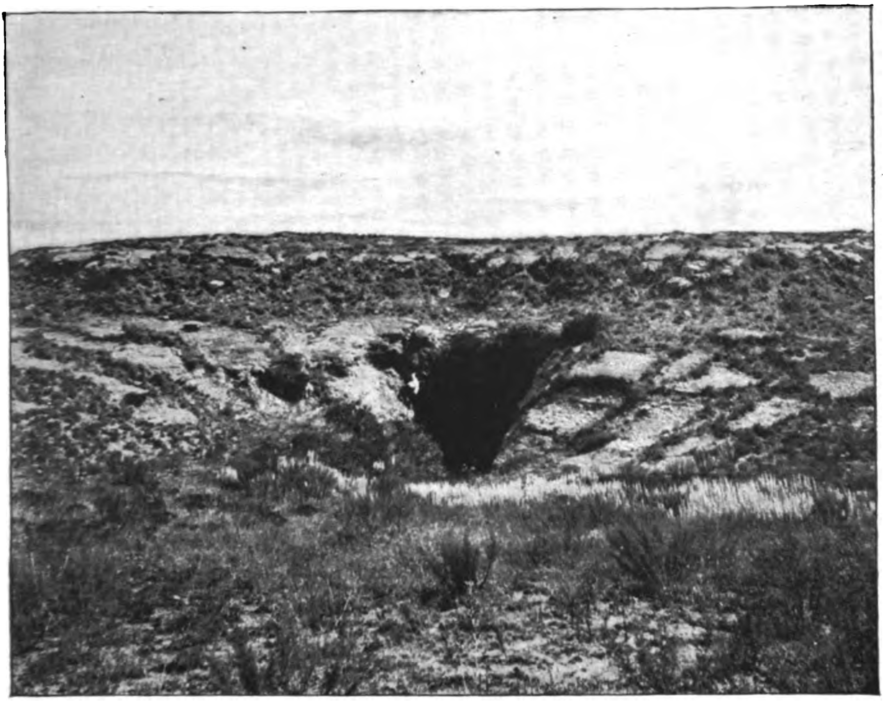
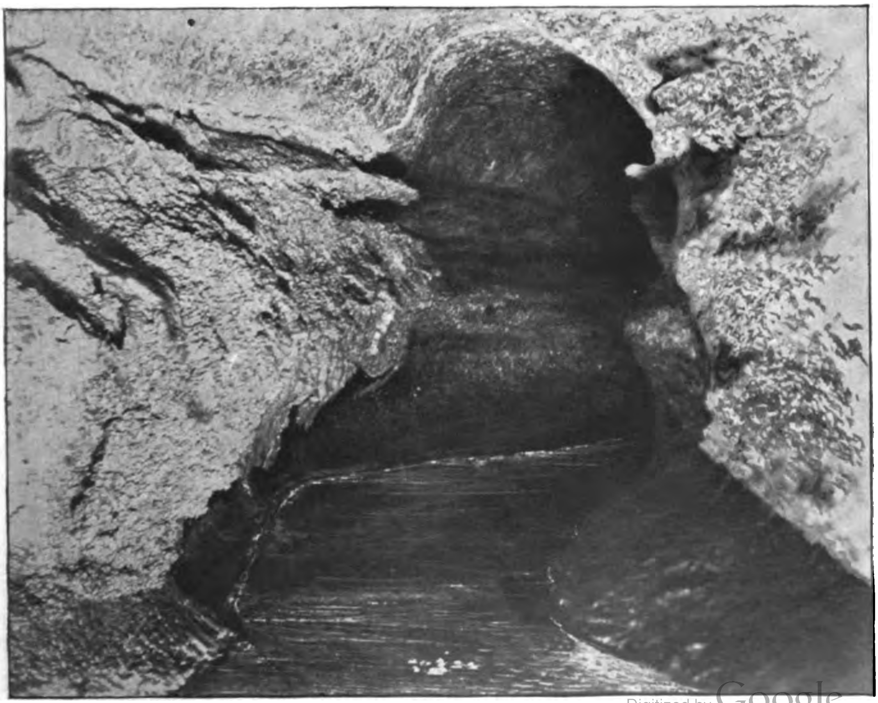
[a] Humphreys and Abbot, Phys. and Hydrol. of Mississippi River, Washington, 1861, p. 136.



A. SINK-HOLE CONNECTION WITH UNDERGROUND DRAINAGE SYSTEM.



B UNDERGROUND CHANNEL.

Absorption takes place both directly and indirectly. In the case of direct absorption the rain falls upon the surface of the rock and the water is absorbed either by its pores or by the fissures or cavities which it may contain. In indirect absorption the water is first directly absorbed into loose unconsolidated deposits overlying the solid rocks, or is gathered into streams flowing over their surfaces. In those cases where the rocks are directly exposed to the rainfall the water which is not immediately absorbed runs off and either enters loose materials or is gathered into the streams as indicated. The unconsolidated materials soon become saturated to a certain level, and the rocks upon which they lie are in this way kept constantly in contact with the water, which is continually absorbed.

In the case of the water entering the sands and gravels the direction of the movement is generally toward the river rather than away from it, but in arid regions, where the rainfall is slight, waters are often absorbed by the gravels from the streams which have come from regions of greater rainfall. The relative amount of water indirectly absorbed by the rocks is far greater than that directly received through rainfall.

PERMEABILITY AND STORAGE CAPACITY OF ROCKS.

Methods of absorption.—The amount of water which enters the rocks or other materials by direct absorption varies greatly with the nature of the materials. The amount absorbed by the porous beds of sands and gravels that occur along stream valleys and along lake shores and the coast is very large. In some regions, as in portions of Cape Cod and Long Island, there are practically no surface streams, the water being absorbed by the soil as soon as it falls and carried to the sea by underground drainage.

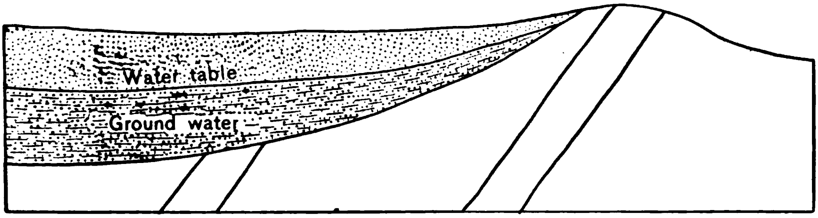


FIG. 2.—Absorptive conditions of outcrop.

Next to unconsolidated deposits, the rocks which present the conditions most favorable for direct absorption are the sandstones and certain of the porous limestones. In the case of the granites, slates, and other massive rocks the direct absorption is very slight.

Besides the character of the material, the amount of absorption depends very largely upon the inclination of the porous beds, the amount being much greater in the gently inclined beds than in those having steep dips. Thus in fig. 3 the two beds represented as outcropping on a level surface present widely different absorptive conditions owing to the difference in area of their absorptive surfaces, the exposed surface of the gently sloping bed (*a′*—*b′*) being several times greater than that of the highly inclined bed (*a*—*b*).

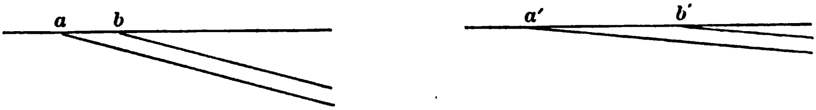


FIG. 3.—Relation of areas of outcrop to dip.

Bedding planes.—Bedding planes are the surfaces separating beds of stratified rock. Where the character of the rock changes, as it frequently does along these bedding planes, the conditions are generally very much more favorable for the passage of water than elsewhere in the rock. The same is true in igneous rocks where two types of rock come together.

Solution caverns.—In a few instances waters enter the ground as definite streams through caverns or other passages formed by the solution of limestone and other similar rock. One of the most commom methods by which water enters the limestones is by means of the depressions known as sink holes. These sinks are due to the caving in of underground caverns which have previously been formed by underground streams. A connection is frequently maintained through these sinks between the surface and the underground channels, and the waters falling on the surface flow into them and pass downward to join the underground supplies. Pl. I, *A*, shows such a sink, while Pl. I, *B*, shows an underground channel in soluble rock.

Faults.—A fault is a plane or fracture which cuts the rocks and along which movement has taken place, resulting in the displacement with relation to one another of the rocks on the opposite sides. Sometimes the fault consists of a single plane, with solid walls on either side, as indicated in fig. 4, *a*, but in many cases there are really a number of parallel planes, very close together, along which slipping has taken place. In such instances the rock on either side has the sheety appearance indicated in the cross section, fig. 4, *b*. In other cases the rocks on either side of the fault plane are completely crushed and the fragments more or less disturbed with relation to one another. In still other cases the fractures are irregular, and the movement of the rocks has been such that projecting points come opposite one another, leaving intervening cavities, as shown in fig. 4, *c*.

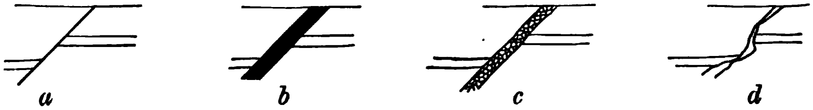
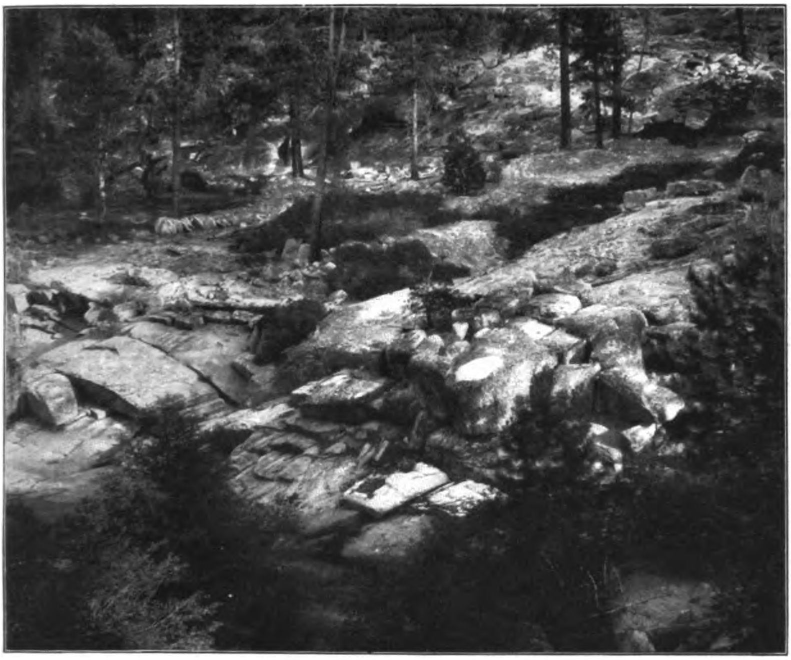
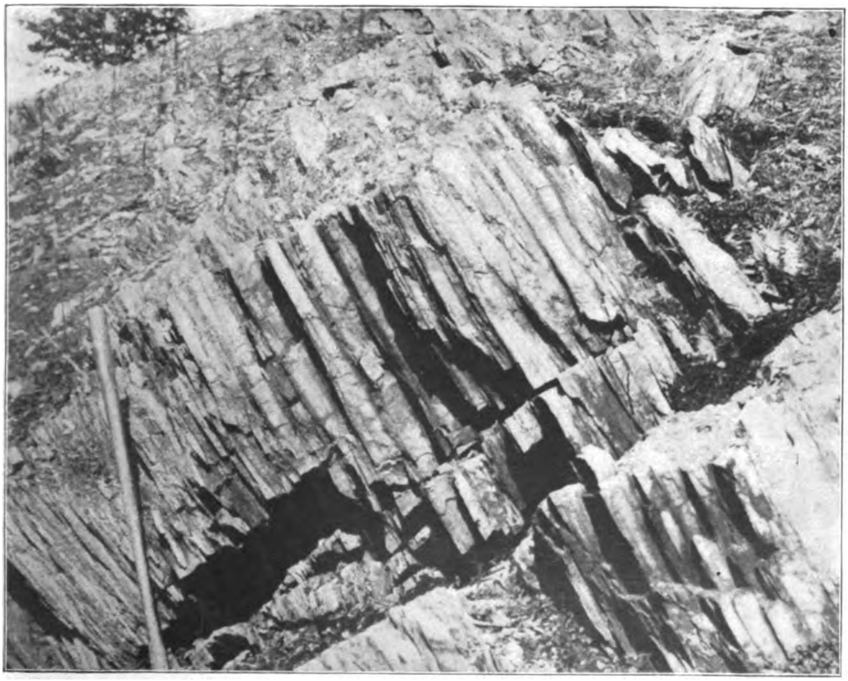


FIG. 4.—Common types of faults.



A. OUTCROP CUT BY JOINT OPENINGS.



B. CLEAVAGE IN SLATE.

The conditions for the passage of water are least favorable in the case of a single definite fault plane. In the sheeted type of faulting the conditions are somewhat more favorable, as there are more surfaces along which the water can penetrate. Along the crushed zones the open spaces are frequently very considerable and permit the passage of large amounts of water. In the case of an irregular fault plane, as in fig. 4, *d*, the conditions are less constant, but in general such a fault will permit of the passage of considerable amounts of water.

Joints.—Joints are smooth fracture planes cutting the rock in various directions. They differ from the faults in that there has been practically no motion of the rocks bordering the plane. They therefore correspond most nearly to the single fault plane described above, nd likewise present relatively unfavorable conditions for the passage of large amounts of water. At the same time water in moderate amounts very frequently passes along such planes, especially along the line of intersection of two or more planes. Pl. II, *A*, illustrates an outcrop of a rock ledge cut by joints in two directions and presents conditions favorable to the absorption and downward passage of water.

Cleavage.—Cleavage is the name applied to the minor planes cutting ne rock. Unlike the joints they usually run in only one direction, and are frequently not actual fractures, but are simply lines along which the rock would tend to split under favorable conditions. Cleavage is best devoloped in fine-grained compact rocks of which the well-known roofing slate is the best example. Pl. II, *B*, shows a number of these cleavage planes in a ledge of this material. Cleavage does not afford as ready a passage for the water as the other features described.

Foliation and schistosity.—Foliation and schistosity are features due to the occurrence of the minerals of the rock in thin plate-like crystals parallel to one another. The arrangement is such that in many instances water passes with some readiness into the rock along the planes formed by layers or laminæ of these crystals.

Porosity.—Porosity is the term given to designate the amount of pores or open spaces between the particles of which the rock is made up. In a general way porosity is determined by the amount of water which the rock is capable of absorbing. The amount varies greatly, being least in the compact igneous rocks and greatest in sandstones and loose sand. In the following table are given the amounts of water which a cubic foot of sand and some common rocks will absorb:

Material.	Water absorbed per cubic foot.	Material.	Water absorbed per cubic foot.
	Quarts.		*Quarts.*
nd	10	Dolomite	1–10
tsdam sandstone	2–6	Chalk	8
assic sandstone	4	Granite	$\frac{1}{100}$–$\frac{1}{4}$
renton limestone	$\frac{1}{4}$–$1\frac{1}{4}$		

Pl. III shows the appearance of two sandstone fragments under the microscope. The black portions in these sections represent what were originally open spaces between the grains.

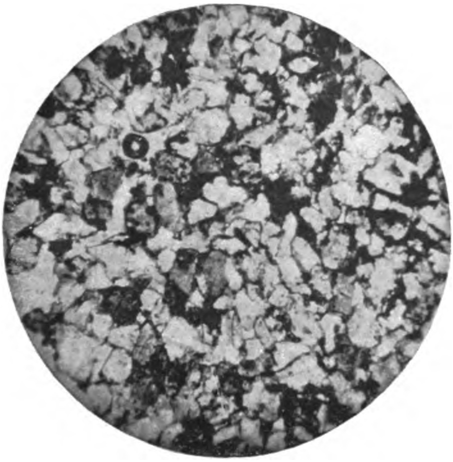
OCCURRENCE AND AMOUNT OF GROUND WATER.

Occurrence.—The underground water which has been derived in the various ways outlined above occurs in the rocks under a variety of conditions. A part occupies the spaces along the bedding, fault, joint, and cleavage planes and a part occurs in the solution channels and caverns dissolved in the soluble rocks. The various fracture planes indicated, while very numerous in the aggregate, nevertheless comprise but a very small proportion of the open spaces within the rock, as they are limited to plane surfaces. The pores, or spaces between the particles which make up the rocks, are, on the contrary, everywhere present throughout the entire mass and constitute by far the larger proportion of the open space in the rock.

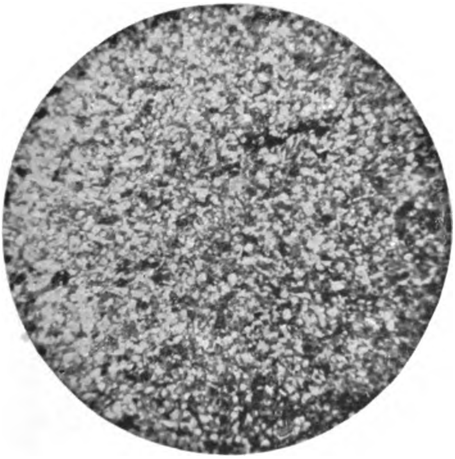
Amount.—In general, it is necessary only to penetrate a few feet of strata to reach a zone saturated with water, the depth depending upon the amount of precipitation, being least in regions of much rainfall and greatest in arid regions.

The downward limit of penetration of the water is dependent upon a variety of causes. It is frequently assumed that all rocks are saturated to great depths, the limit to which the water will penetrate being assumed to be that point at which the weight of the rock becomes so enormous that pores between the particles can not exist. This limit has been placed at about 6 miles. Practical experience in well drilling, however, shows that the assumption that all rocks are saturated below a moderate depth is far from being substantiated. In the Pennsylvania and New York oil regions, for instance, it is a very common experience to encounter, at a depth often of only a few hundred feet, rocks which are practically destitute of water. These include coarse-grained open sandstones, capable of holding large amounts, yet as far as can be determined they are absolutely dry, it being necessary in many instances to pour in from the top the water necessary for the process of drilling. In some instances after passing through these water-free rocks salt waters are encountered, but it is very rarely the case that fresh waters are found below the dry series. In some instances wells have been drilled several thousand feet without encountering any water whatever below the first few hundred feet. Although the rocks are far from being saturated, slight amounts of moisture are doubtless held in the pores.

Notwithstanding the fact that the depths to which the waters penetrate in quantities are probably much less than is frequently assumed, there is, nevertheless, an enormous amount of ground water. It has been estimated that the average pore space of the surface rocks is



A



B

SANDSTONES VIEWED UNDER THE MICROSCOPE.

about 10 per cent of their volume, but 5 per cent will probably be found to be more nearly correct.

WATER-BEARING FORMATIONS.

All rocks contain more or less water which, as pointed out, occupies either cavities in the rock or occurs between the minute pores. The water which occurs in the pores is given up readily only in the coarser rocks, such as sandstones, the fine-grained rocks yielding very little of such water when penetrated by the drill. In these rocks, the water, when found, usually comes from the joint, fault, or foliation planes. The conditions of the occurrence of water in the various rocks are very variable and are described in the following pages.

Sand and gravel.—Sands and gravels are very porous, 30 per cent of their volume frequently being made up of free space between the grains. In such materials the whole mass is saturated with water below the water level, and when penetrated by wells copious supplies are quickly yielded. The waters are generally of good quality, but are sometimes somewhat mineralized, the material being derived from the more soluble fragments and particles which constitute the deposits.

In passing downward through the sands surface waters are subjected to natural filtration, especially in the finer varieties, and the substances with which they may have originally been polluted are frequently removed. In the coarser types of sand, and in gravel, the water passes downward more rapidly, the conditions are less favorable for filtration, and the waters may remain polluted. In general, however, waters from sand and gravels, if taken from a considerable distance below the surface, are safe to use.

In the sands and finer gravels the cheapest and best method of obtaining water is by driven wells, which can be sunk quickly and at a very slight cost. In the very fine sands or quicksands, however, it is very difficult to exclude the material from the pipes, the quicksand frequently penetrating the well and clogging the pipe or ruining the pump. Because of the readiness with which sands and gravels yield their water, wells located close together frequently affect one another, the lower well or the wells which draw from the sand at the lowest points drawing the water from the higher wells. The readiness of movement of the water is also the cause of important fluctuations of level of the surface of the saturated zone, the water level often falling rapidly after wet seasons. To secure permanent supplies the wells should penetrate to the level which the water surface occupies in the driest seasons.

Clay.—Clay is very impervious to water, and in itself contains little or none which can be utilized as a source of supply. Water, however, is frequently reported in clays, but usually comes from more or less sandy layers. In some cases sand which approaches clay in fineness, and which is sometimes mistaken for clay, yields considerable amounts of water. Clay is of the greatest importance, not as a water-bearer but as a confining layer to porous sands, from which it prevents the water from escaping. The waters of clays, because of the fineness of the material, come into contact with relatively large amounts of mineral matter and frequently become mineralized, lime and salt being the most common substances dissolved. The waters of clays are, as a rule, free from contamination. When, because of the absence of other sources, it is necessary to obtain supplies from clay, a well should be sunk with as large a diameter as possible and continued beneath the point at which the water is obtained to a sufficient depth to furnish ample storage capacity, as clay waters are slight in amount and are yielded very slowly. Dug wells are usually most satisfactory where the clay is near the surface, but such wells should be carefully covered and guarded from all sources of pollution (see fig. 5).

Till.—Till is a heterogeneous mixture of clay, sand, gravel, and bowlders, deposited by glaciers in the northern portion of the country. In texture it varies from porous to impervious according to whether sand or clay predominates. It is seldom definitely bedded. The water generally occurs in small more or less tubular channels a few inches in diameter, but occasionally is distributed through interstratified sandy beds.

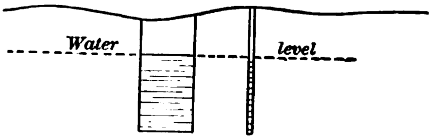


FIG. 5.—Relative size and storage capacity of dug and drilled wells.

In the aggregate the till yields a large amount of water, being the source of supply in the rural districts at a great number of points throughout the entire northern portion of the country. Because of the occurrence of the water in definite channels, however, the success of wells varies greatly. In general, wells of large diameter, similar to those described in the preceding paragraph, give the best success. Fig. 5 represents two wells of the same depth, one of the dug type and one of the bored type. It will be seen that in the well of the dug type not only is a larger amount of material encountered in cross section, but that the area of surface from which water can enter is many times greater than in the well of the bored type. The open well also presents larger storage possibilities, it being thus possible to utilize small supplies, which would be insufficient in the case of the bored well.

The water of the till is generally uncontaminated because in its downward penetration through the clay of which the till is in part composed it is subjected to natural filtration. If the water becomes polluted, however, it may retain its dangerous character for a long period of time and for considerable distances.

Sandstone, conglomerate, and quartzite.—Sandstone is on the whole the best water-bearer of the solid rocks. Under the most favorable conditions the rock is saturated throughout its extent below the regular ground-water level, and water is yielded wherever the sandstone is struck by the drill within these limits. The water is yielded freely as a rule, although in some of the finer-grained sandstones it flows less readily. In quality the water averages better than in any other material except sand and gravels. It is almost never polluted, and wells can generally be safely used if they are cased to keep out the surface waters. The drilled type of well is utilized except where the sandstone is very near the surface.

Conglomerates sometimes furnish considerable water supplies, although as a rule their absorptive powers are not so great as those of sandstones, and they are much less frequently encountered. Quartzite is a sandstone in which the spaces between the grains have been filled by hard, siliceous matter. Because of the filling of the pores by this material there is relatively little chance for the water to enter, and the rocks are not commonly an important source of water.

Slate.—Slate, like clay, is a poor water bearer, but may yield water from bedding, joint, cleavage planes, etc. Its most important use, however, is as a confining layer to prevent the escape of water from porous sandstones which may be interbedded with it. The waters are reached by deep wells and are generally uncontaminated.

Limestone.—The waters of limestone occur mainly in open channels, caverns, etc, dissolved in the rock by the water itself. The water originally probably followed joint or bedding planes, which were gradually enlarged by solution into the caverns which we now find.

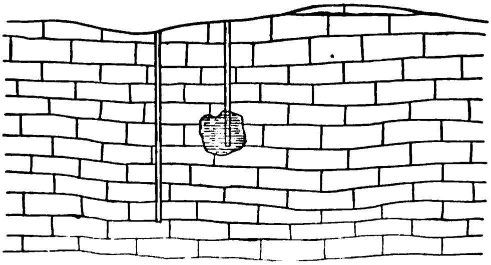


FIG. 6.—Difference in conditions of adjacent wells in limestone.

The occurrence of caverns and passages within the limestone is very irregular and their location can seldom be predicted. Most deep wells, however, which are drilled in limestone regions encounter one or more such passages at a relatively slight depth from the surface. Wells, even where only a few feet apart, nevertheless often obtain very different results, as a difference of a foot or two frequently means the missing of a certain channel, as indicated in fig. 6. The waters are generally hard, but are not commonly otherwise mineralized. There is, however, a considerable likelihood of pollution, due to the fact that much of the waters of the underground streams in the limestone have found their way downward through sink holes, carrying with them more or less surface wash (see Pl. I, *A*).

Granite, gneiss, and schist.—The granites and gneisses are very dense and possess very small pore spaces, and the body of these rocks hold very little water. In schists, however, considerable water often penetrates along the foliation planes and is held by the rock, but such water is given up very slowly and is not of importance as a source of supply.

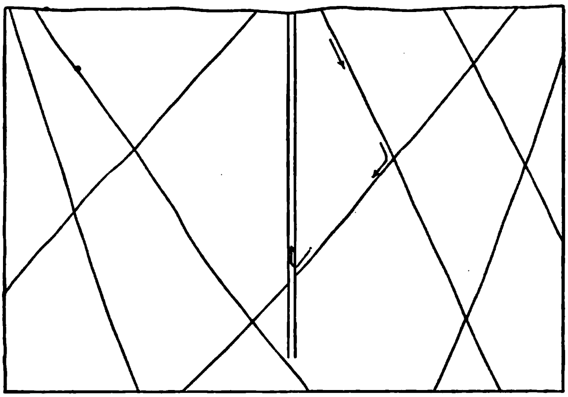


FIG. 7.—Well in jointed rock.

It is along the joints that the largest supplies are obtained. These joints are most common near the surface and diminish in number and in definiteness as depth increases. For this reason the water supplies, if obtained at all, are generally found within 200 or 300 feet of the surface. It is generally useless to go deeper than 500 feet for waters in these crystalline rocks, although in some instances, as at Atlanta, water supplies have been obtained at depths as great as 1,600 feet. The joints generally occur in complex systems of intersecting planes, and it is possible for polluted water starting very near the mouth of the well to pass in a zigzag course downward along the joints, finally reaching the well at a depth of many hundred feet (fig. 7), as was the case in a well at Atlanta, Ga., which finally had to be abandoned. For this reason wells drilled in igneous rocks in cities and other thickly populated regions are liable to become polluted. Waters from such wells, if they are to be used for drinking purposes, should be tested occasionally to determine the possibility of pollution.

TEMPERATURE OF UNDERGROUND WATERS.

In all wells there is a certain depth, which differs in different localities, at which there is practically no difference in the temperature of the water from season to season or from year to year. This is known as the normal temperature of the water for a given region, and it agrees very closely with the mean annual temperature of the same locality. The depth of uniform temperature varies somewhat in different localities, but is commonly from 50 to 60 feet below the surface. The temperature varies from about 40° or 45° in New England to about 65° or 70° in the Gulf States.

Waters occurring nearer to the surface than the zone of uniform temperature vary in temperature according to season, being warmer than the normal in summer months and colder in the winter months. The temperature of waters warmer than the normal may also be due to the great depth from which the waters have come.

The main cause of rise in temperature below the line of invariable temperature is the internal heat of the earth. This internal heat increases rapidly downward, the rate of increase varying from 1° in 30 feet to 1° in 100 feet, the average increase being about 1° to 50 feet. The temperature of the water is very little affected in passing through the upper 50 feet of its course, hence its temperature is a fair indication of the depth from which it is derived.

Besides the internal heat of the earth the heat of igneous masses below the surface of the earth has been thought to give rise to the hot springs of many localities, and in some instances the heat evolved by the chemical decay of rocks has been cited to explain the temperature of hot springs.

RECOVERY OF UNDERGROUND WATERS.

Water is returned to the surface in three general ways: (1) By seepage, (2) by springs, and (3) by wells. A brief discussion of each method is given in the following pages.

SEEPAGE.

Although a relatively obscure method, seepage is of great importance in returning water to the surface, especially in sands and gravels. Seepage water does not occupy definite channels, but fills the pores between the component grains of the various surface or other deposits. It emerges at the surface whenever the water level within the deposits becomes, through additions from rainfall, etc., higher than that of the lowest depressions or level of the surface. Sometimes, as on the south side of Long Island and elsewhere, the waters seep out from the sands over extensive areas along the shores a few feet above sea level. In such places the water frequently does not gather into definite channels, but forms more or less extensive fresh marshes, and gradually works its way into the sea. More frequently, however, seepage waters emerge in stream channels and other depressions. In some cases the water enters the stream at or just above the surface, but in most instances the main supply enters below the water level along the sides and bottom of the channel.

The distinction between seepage and springs is not sharp. The term "spring" is usually limited to those occurrences where the water comes out at a definite point, or at least emerges from a restricted area, but water that often appears at the surface as general seepage is often found, on excavating at its point of emergence, to come from a definite channel, and to approach a true spring in character.

SPRINGS.

Springs are not only exceedingly numerous throughout large portions of the eastern United States, especially in the more rugged regions, but form a most important source of water supply. In many of the hilly districts they constitute, in fact, almost the only source of domestic supply. In general they are free from pollution and not too strongly mineralized for ordinary uses. Mineral springs, however, are not uncommon, and are much used for medicinal and table purposes, and have lead to the development of sanitariums and many large and popular pleasure resorts.

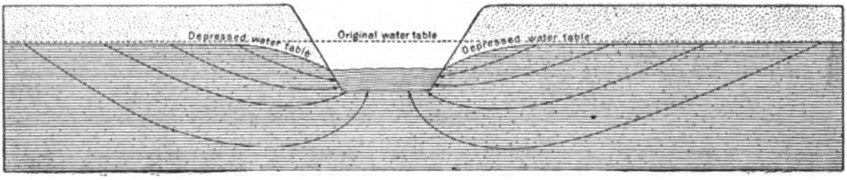
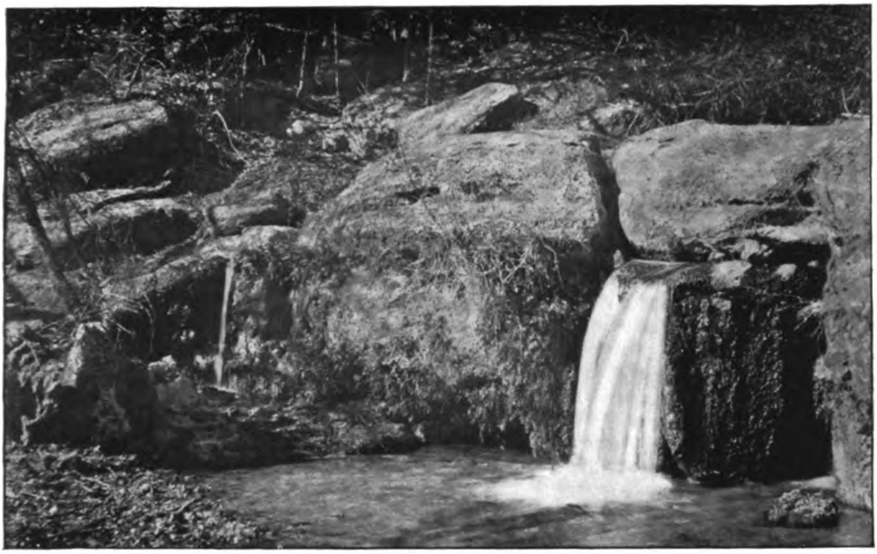


FIG. 8.—Lines of underflow into channel.

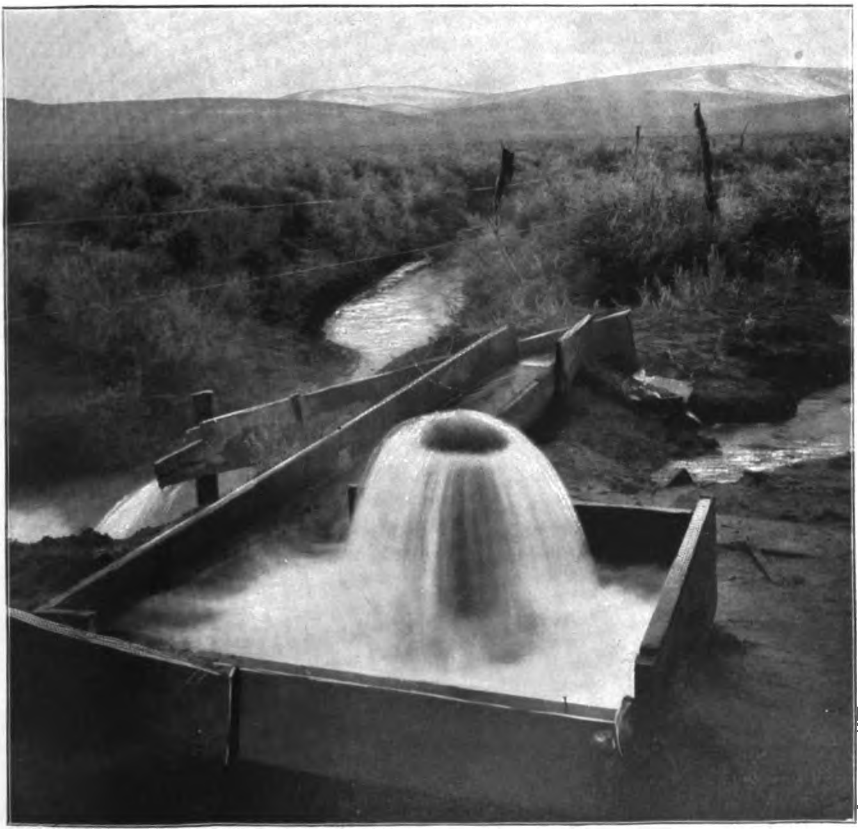
Seepage springs.—This term is applied when the water seeps out of sand or gravel, and differs from general seepage only in that it is restricted to a very small area. Such springs are usually marked by abundant vegetation at points of emergence, and the water as it collects is often colored or carries an oily scum due to the decomposition of vegetable matter. The scum is often mistaken for petroleum. Before using such a spring the vegetation should be cleared away and a small reservoir constructed, or tank sunk in the ground.

The waters of the seepage springs usually come from no great distance beneath the surface and are not usually very cold. Being fed by waters coming from near the surface they are sometimes likely to become polluted, and local conditions should be carefully studied before the water is used for drinking.

Seepage springs sometimes emerge along the top of an underlying impervious bed, but more frequently occur where valleys are cut downward into the zone of saturation of a more or less uniform water-bearing deposit, or where the water table comes to the surface near a stream, a lake, or the sea. Under favorable conditions the seepage from sands, as on Long Island, gathers into channels and forms streams of



A. SPRING FORMED AT OUTCROP OF AN IMPERVIOUS FLOOR.



B. ARTESIAN WELL.

considerable size, some of them flowing 5,000,000 gallons or more daily.

Springs from definite underground channels.—In this group is embraced a great variety of springs, including both those flowing in the small more or less tubular passages in the drift, and those occupying large solution channels or caverns in the soluble rocks.

The channels of the drift springs are generally established along some more or less sandy or other porous layer, or even in places along the path left by a decaying root. At first the motion appears to be mainly by seepage, but in many instances a passageway is gradually opened along which a definite stream finds its way. The waters reach the channels by percolation through the clays and sands, and are usually free from pollution. If such a channel, however, leads from a cesspool, or similar source of pollution, the water becomes highly charged with matter dangerous to the health. Once contaminated it is likely to continue so for long distances, as little natural filtration takes place, owing to the nature of the channel. The water should be thoroughly tested by a chemist if there seems any likelihood of contamination.

In limestones and other soluble rocks the underground passages are often many miles in length. Single passages, as in the Mammoth Cave of Kentucky, have been traversed for a distance of nearly 10 miles, while passages as yet undiscovered, but several times as long, probably exist. Some of these passages are many feet in diameter and are traversed by streams of considerable size, or even rivers. The Silver Springs of Florida give rise to a river which is navigable from the ocean to its source in the springs, while springs of similar volume occur elsewhere in Florida and Arkansas, and possibly elsewhere. The waters of such springs vary greatly in composition. although most of them are hard. Some waters are exceedingly clear, the bottoms of springs being distinctly visible at a depth of many feet, but in others the waters are muddy after severe storms. In the first case it is probable that the waters feeding the underground stream reached it by percolation through the porous earth or rock, during which its impurities were largely removed. In the second case the waters in part appear to have penetrated downward through sinks, or entered the rock directly as streams. In both cases they are very liable to pollution by impurities washed in with the water (see Pl. I).

Fissure springs.—The term fissure springs is here used rather comprehensively to include the springs issuing along bedding, joint, cleavage, or fault planes (Pl. IV, *A*). The distinguishing feature is a break in the rocks along which the waters can pass, it being immaterial whether any considerable open space exists. These springs differ from the preceding in that they are as a class of deeper-seated origin. Seepage and drift springs are largely confined to unconsolidated surface deposits, while the channels of limestone springs do not ordinarily extend much below the level of the surrounding surface drainage. In fissure springs, on the other hand, the waters are frequently derived from great depths, as is attested by their temperatures. The waters are almost never subjected to contamination, but are, however, often highly mineralized. Springs of this class are often scattered along straight lines for considerable distances, their position being determined by lines of fracture or jointing, as shown in fig. 9.

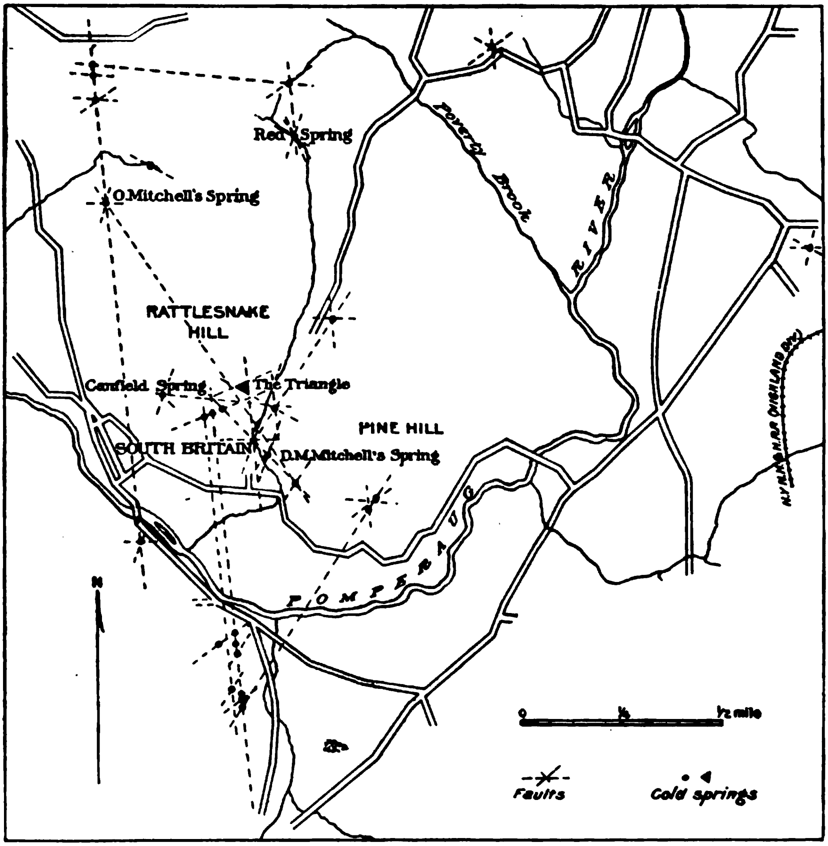


FIG. 9.—Map showing location of springs along faults or joints near South Britain, Conn. (After Hobbs.)

Geysers.—Geysers are those springs in which at more or less regular intervals the water is ejected with some force. The waters are always warm or hot and, therefore, come from considerable depth. Geyser springs generally emerge from tubular conduits that are lined with silica, deposited by the water, and end at the surface in a cone of similar material. The ejection of the water is probably due to the expelling force of steam generated deep below the surface under certain peculiar conditions.

WELLS.

Wells are of three general classes: (1) Dug, (2) driven, and (3) drilled or bored. A few paragraphs will be devoted to their consideration, but detailed discussions will not be attempted.

Dug wells.—Dug wells are especially adapted to loose unconsolidated surface deposits in which the water supply is rather scanty. They present a large surface from which the water can enter and have a large storage capacity, but, on the other hand, they must necessarily be of limited depth, and because of the difficulty in keeping out surface and shallow-soil waters and other materials, are especially liable to pollution. They are also quite expensive and need to be frequently cleaned. They are undesirable if sufficient supplies can be had by driving or drilling.

Driven wells.—Driven wells consist of a pipe, with strainer and pointed end, which are driven into sand and similar soft deposits. They can be put down in a few hours, are exceedingly cheap, and effectively exclude surface waters. The principal difficulty arises from the penetration of sand and the clogging of the pipe. Driven wells furnish ideal supplies in many sandy regions, but are, of course, not adapted to the conditions existing over the greater part of the country.

Drilled and bored wells.—These include those wells drilled by machinery in rock or other deposits. Many different methods of drilling are employed, the one used at a particular point depending upon the material to be encountered or upon the nature of the well demanded. Among the most common are: (1) The ordinary churn-drill method, in which the drill is rapidly lifted and dropped, forcing its way down by impact; (2) the diamond-drill method, in which a cylinder set at the bottom with diamonds is rotated, cutting out a core of the rock; (3) the steel-shot method, in which loose chilled steel shot takes the place of diamonds, and (4) the jet process, in which a current of water is forced from the lower end of the pipe and by loosening the surrounding material allows the latter to sink. Many other methods or modifications are in use. Pl. IV, *B*, represents one of the deep drilled wells yielding flowing water.

PUMPS.

In raising water to the surface a variety of methods are used, but except for the bucket of the open wells they all depend upon some type of pump. Of the hand pumps, the ordinary valve pump, the chain pump, and the force pump are the most common. For raising large supplies windmills usually afford a cheap and satisfactory method on the farm, but in industrial establishments, where not only a large but a constant and steady supply is needed, some form of power pump is used. Electricity, steam, and gasoline are all used, the latter being especially popular because of cheapness and ease of operation. Various forms of "air-lift" processes, by which water is lifted by a current of air that is forced into the well tubing, are successfully used.

ARTESIAN FLOWS.

ESSENTIAL CONDITIONS.

Stratified beds.—In 1885 Prof. Thomas C. Chamberlin, in a paper entitled "Requisite and Qualifying Conditions of Artesian Wells,"[a] explained the principles of artesian flow, and called attention to many of the special conditions which tend to determine the success or failure of these wells. The conditions which, according to Professor Chamberlin, may properly be considered as those of true artesian flow are as follows:

I. A pervious stratum to permit the entrance and the passage of water.
II. A water-tight bed below to prevent the escape of water downward.
III. A like impervious bed above to prevent the escape upward, for the water, being under pressure from the fountain head, would otherwise find relief in that direction.
IV. An inclination of these beds, so that the edge at which the waters enter will be higher than the surface at the well.
V. A suitable exposure of the edge of the porous stratum, so that it may take in a sufficient supply of water.
VI. An adequate rainfall to furnish this supply.
VII. An absence of any escape for the water at a lower level than the surface at the well.

Some of the features outlined above are illustrated by the following diagrams taken from Professor Chamberlin's report. There are many other minor conditions and modifications of the requisites outlined above which bear on the occurrence of artesian waters, but the essentials are here given.

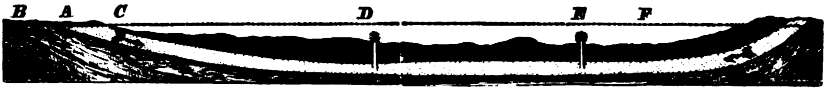


FIG. 10.—Section showing principal requisites of artesian wells. *A*, a porous stratum; *B*, *C*, impervious beds below and above *A*, acting as confining strata; *F*, height of water level in porous beds *A*, or, in other words, height of reservoir or fountain head; *D*, *E*, flowing wells springing from the porous water-filled bed *A*.

Joints and faults.—Flowing water is not confined to those wells which penetrate beds under the conditions outlined by Professor Chamberlin. The principle on which artesian waters depend is equally applicable to other rocks, the essential feature being simply that the water be confined and that the outlet through the well be considerably lower than the catchment area at which the water entered. A bedding, joint, or fault plane, or other fissure in insoluble rocks, or a solution passage in limestones, sometimes affords favorable conditions for artesian flows, although because of their commonly limited development they are far less frequently encountered than the broad porous sandstones and other sedimentary beds.

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[a] Fifth Annual Rept. U. S. Geol. Survey, pp. 125-173.

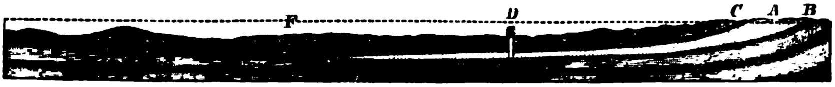

FIG. 11.—Section illustrating thinning out of porous water-bearing bed *A*, inclosed between impervious beds *B*, *C*, thus furnishing conditions for artesian well *D*.

Besides occurring along bedding planes or along joint or fault planes water frequently follows a combination of passages, such as indicated in fig. 13, which shows an inclined bed cut by a joint, the motion of the water being indicated by the arrow. Exactly the same conditions might occur if the bed *b* were to be replaced by a joint or fault plane of the same position.

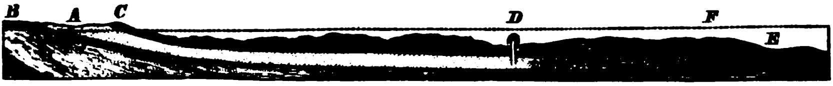

FIG. 12.—Section showing transition from porous to impervious bed. *A*, a close-textured, impervious bed, inclosed between impervious beds *B* and *C*, furnishes conditions for an artesian well *D*.

Direction of movement of water.—In the majority of cases the water encountered by wells is moving down the dip of the beds or down the joint or fault line, but in many instances, as in the cases outlined above and illustrated in fig. 13, the water may be moving upward.

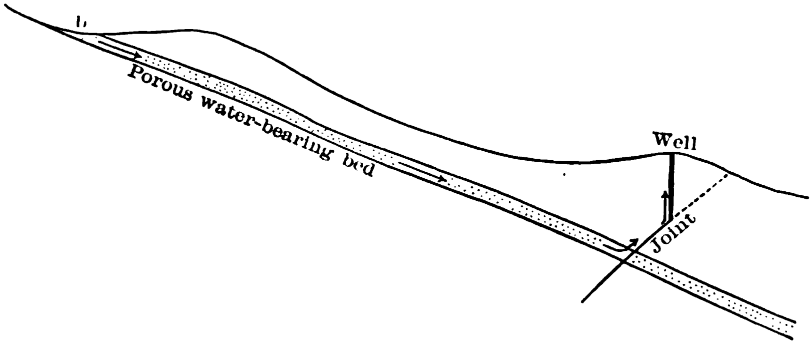

FIG. 13.—Upward circulation of water along joint.

UNDERGROUND WATER CONDITIONS IN EASTERN UNITED STATES.

There are great differences in the underground water conditions in different parts of eastern United States. These are due in part to the presence in the northern half of a mantle of surface deposits left by glaciers or by streams connected with the ice. A part of the difference is also due to the difference in weathering of the rocks in the northern and southern portions, while still another part is due to variations in the character of rocks and of topography.

AREA OF GLACIAL DRIFT.

This area is bounded on the south by a line which, starting at Nantucket, passes through Marthas Vineyard, Long Island, across New Jersey, northwestward across Pennsylvania into New York, then southwestward across Pennsylvania and Ohio to the vicinity of Cincinnati, where it crosses the river for a short distance into Kentucky,

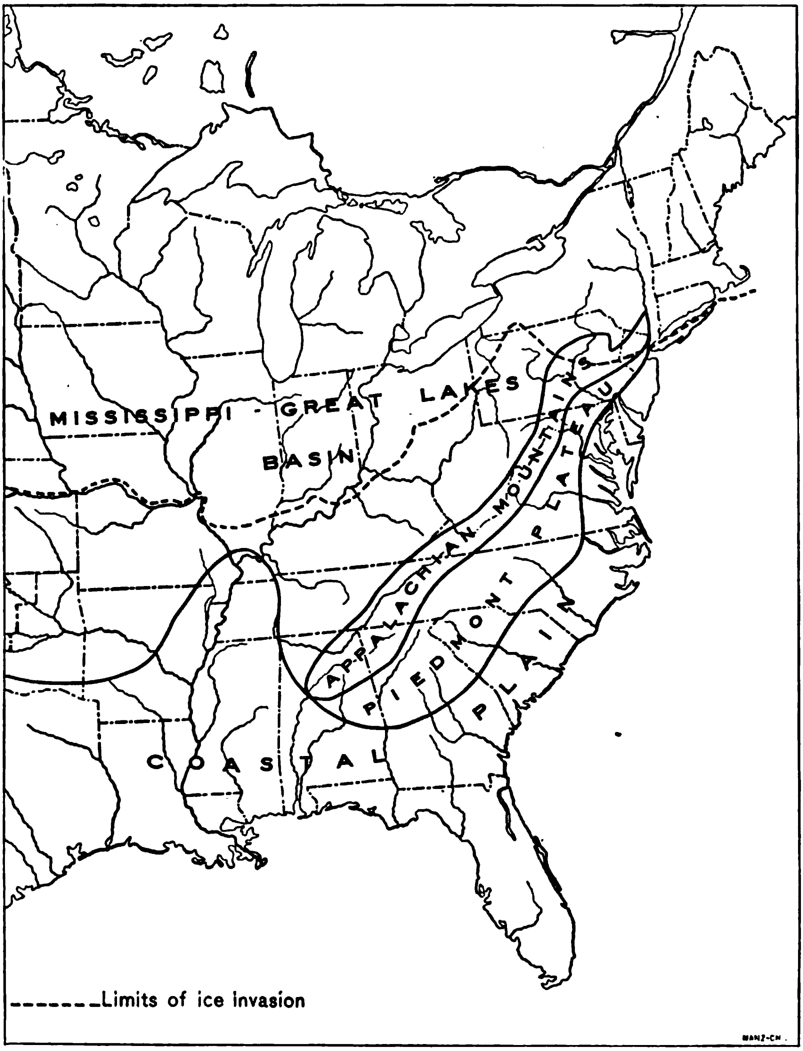

FIG. 14.—Geologic and water-supply districts in eastern United States.

thence westward across southern Indiana, Illinois, and central Missouri, to a point near Kansas City, where it leaves the region under consideration (see fig. 14). All of the region north of this line was covered one or more times by great ice sheets, except a small area in southwestern Wisconsin and adjacent portions of Minnesota, Iowa, and Illinois, where there appears to have been a sort of island of land surrounded by ice, known as the "Driftless area."

North of the boundary mentioned the surface, except for the small driftless area, is covered with a mantle of materials deposited by the glacier and known as drift. The drift is divided into two main types, the first known as till, and the second as modified or stratified drift. Till is composed of a heterogeneous mass, consisting of clay, sand, and bowlders, frequently known as hardpan. It was deposited mainly directly by the ice, either beneath the sheet or at its margin. The second class of drift includes gravels, sands, and other stratified deposits formed by streams leading outward from the ice sheet. It is found chiefly along the valleys which were once occupied by glacial streams, but considerable amounts were also deposited in temporary glacial lakes which existed between the northward sloping land and the retreating ice sheet, while some was laid down as broad wash plains.

The glaciers which left the various types of drift started in the far north in relatively recent geologic times and spread southward to the limits mentioned. Before their advance the rocks were probably deeply weathered and covered with soil, as in the South at the present time, although the extent of the weathering was doubtless somewhat less. The first work of the ice was to remove this soft weathered material. Part was incorporated with the till and part was carried off by the streams to form clay and sand deposits. Later, after the removal of the surface soil, the glacier began the work of wearing down the solid rocks, plucking off fragments both large and small from the ledges and transporting them southward. This material was also left in part in the till, and in part carried away by the streams.

The effect of the drift on the water supply of the northern portion of the country is very great. In general the drift holds very much more water than any of the rocks. This water is yielded readily to shallow wells, and furnishes by far the larger part of the well supplies in the region where it occurs. Water is least abundant in the till and most abundant in the stratified drift. Its occurence in till and in sand and gravel has already been described (see pp. 25–26).

WEATHERED ROCKS.

South of the limits of glacial advance the place of the drift is partly taken by the weathered or decomposed rocks. The weathering seems to be deepest in the south where the climate is more humid and, therefore, more favorable to rock decay.

The soils south of the drift limits consist of small fragments or particles of disintegrated rocks. They are usually colored red and yellow by weathering and are very porous, absorbing much water. Their thickness, however, is not sufficient to make them a good source of water supply, although they yield water to many shallow wells. The water is subjected, as in sands and similar materials, to more or less complete filtration in its passage downward.

ROCK WATER PROVINCES.

Leaving out of account New England and eastern New York, which compare most nearly with the Piedmont Plain, the main divisions of the eastern United States, viewed from the standpoint of underground water supplies, are: (1) The Coastal Plain, (2) the Piedmont Plateau, (3) the Appalachian Mountains, and (4) the Mississippi and Great Lakes basin. The limits of these divisions are shown in fig. 14.

Coastal Plain.—The Coastal Plain consists of a strip of unconsolidated deposits, extending from Long Island on the north along the Atlantic and Gulf States into Mexico on the south. The width varies from a few miles at the north to several hundred miles in the Mississippi River region.

The surface of the Coastal Plain is low, usually not exceeding 100 to 300 feet above sea level and, where uncut by erosion, is generally flat. Owing to the soft character of the materials, however, the streams have generally cut fairly deep valleys which are separated, where not too close together, by flat-topped ridges marking the original surface. Where the streams are close together the surface is cut into rolling hills.

The materials include clays, sands, gravels, marls, and a few more or less solid limestones, the latter being present mainly in the Southern States. A few of the sandy layers have been consolidated and now form sandstones. The beds dip gently toward the coast. The waters in the North occur mainly in sands and gravels, especially in those at the base of the Coastal Plain deposits. Farther south, particularly in the Gulf States, water is found both in sands and in the porous limestones. The quality of the water in the gravels in the northern portion of the belt is generally soft and good, but farther south, notably where sands and gravels alternate with clay or limestone beds, the waters are often hard or are charged with sulphur and iron. The capacity of the wells is generally large and many of them flow without pumping. In the aggregate there are several thousand deep wells scattered throughout the Coastal Plain. They are used principally for domestic and farm supplies, but some of them that yield soft waters are utilized for industrial purposes. In the Gulf States, especially in Louisiana, a large number of wells furnish water for the irrigation of rice. A considerable number are also used as a source of public water supplies.

Piedmont Plateau.—The Piedmont Plateau proper consists of a belt of crystalline rocks, including a few small basins of Triassic sediments, that extends southward from southeastern New York along the east front of the Appalachian Mountains to Alabama, lying between the mountains and the Coastal Plain. Where the plateau joins the Coastal Plain its elevation is only a few hundred feet, but the altitude of its surface increases gradually toward the northwest, until at the base of the mountains, especially in western North Carolina and vicinity, its highest points have an altitude of several thousand feet. In the main its surface, where uncut by streams, is flat or gently rolling, but in its higher portions it has been cut into a series of prominent mountains. In the vicinity of the streams near the coast it is also cut into a series of lower hills, as in the case of the Coastal Plain.

The rocks of the Piedmont Plateau proper consist mainly of schists, gneisses, granites, and other metamorphic or igneous rocks, all of which are of crystalline texture. The rocks of the Triassic basins consist mainly of sandstones, shales, etc.

The waters of the Piedmont Plateau are relatively uncertain in occurrence, depending largely on the existence of joints or other fissures in the rocks, but good supplies have nevertheless been obtained at numerous points. In composition the waters are usually fairly good, although they sometimes contain considerable mineral matter. Relatively few deep wells have been sunk in this region, owing to the uncertainty of supply, dependence being placed largely on streams or on shallow wells dug in the weathered upper portion of the rocks. The waters are used largely for domestic and farm purposes and in small industrial establishments. In a few places public water supplies are obtained from the Piedmont rocks, and some important mineral springs are found in the region.

Similar to the Piedmont Plateau are the great areas of igneous rocks in Minnesota and Wisconsin and in New York and New England. The topography of the rocks in these regions is in general somewhat more rugged than in the Piedmont Plateau proper, and less use is made of the waters, largely because of the abundance of lakes, springs, and spring-fed streams, or of waters in the glacial drift which overlies the crystalline rocks in this portion of the country.

Appalachian Mountains.—The Appalachian Mountains may be considered as beginning in eastern Pennsylvania and extending southward to central Alabama. The Berkshire Hills in Connecticut and Massachusetts and the Green Mountains in Vermont are included in the area by some. The rocks throughout the region are strongly folded and broken by faults, the harder beds giving rise to the great mountain ridges which characterize the belt. The rocks consist of quartzites, sandstones, shales, and limestones. The sandstones and certain of the limestones carry considerable amounts of water, but are seldom used as a source of supply. The water in the limestones is carried in definite channels and is of rather uncertain occurrence. Both the sandstones and limestones yield copious springs in places. Wells in the synclines or rock troughs frequently yield water which will sometimes rise to the surface, but in general dependence is placed on the springs which occur in large numbers throughout the belt. In the wider limestone valleys wells or cisterns are often used. There are very few cities or large industrial establishments in this region and deep wells are therefore somewhat rare.

The Mississippi-Great Lakes basin.—This basin includes the remaining portion of the territory in the eastern half of the United States. The surface is moderately low, seldom exceeding 1,000 feet in elevation, and is usually not characterized by prominent hills or mountains. Except in the areas of igneous rocks, noted above, the rocks consist of flat or very gently folded sandstones, limestones, shales, etc., varying from Cambrian to Carboniferous in age. The Cambrian and other of the older sandstones carry large amounts of water, which is obtained by wells that frequently flow at the surface. The Silurian limestones also contain considerable water, but, as is the case with water in limestones elsewhere, its occurrence at a particular point can seldom be predicted.

The younger rocks, including the Devonian and Carboniferous, consist to a considerable extent of alternations of shales, shaly limestones, and sandstones. In the limestones the water occurs very much as in other limestones. In the sandstones and shales, however, its occurrence is uncertain owing to the lack of persistence of the beds. One well may obtain water, while another a few feet away may fail. The waters are often mineralized, especially in Michigan, where they contain a high percentage of salt. The Carboniferous limestones abound in springs, some of which are of great size.

MAINE.

By W. S. Bayley.

TOPOGRAPHY AND GEOLOGY.

The surface of Maine consists essentially of an extensive southward-facing slope draining directly into the Atlantic Ocean and a smaller northward-facing slope draining into St. John River. The latter area is a great plain covered largely by swamps and interrupted by a few irregular-shaped hills. The surface of the southern slope is much more broken. It is crossed by many ridges of low mountains trending east or northeast, some of which rise several thousand feet above the platform on which they rest. These are separated by wide areas of plain, on which are many small glacial hills and ridges. Near the coast the surface is rough. Rocky ridges and low, bare hills stretch from the shore line some miles inland, but the hills are not lofty and the valleys between them are not deep.

All the rocks are Paleozoic or older, except the very late marine clays and the glacial deposits. The northern portion of the State is underlain by moderately folded Silurian and Devonian limestones, shales, and sandstones, cut here and there by igneous rocks, some of which are certainly volcanic. In this area the conditions are the most favorable for the occurrence of artesian waters.

The section bordering the coast is underlain by granites, gneisses, crystalline schists, and ancient lavas intersected by intrusives. The central portion of the State, between the northern and the coast belts, is composed of slates, quartzites, and impure limestones, very much like the rocks in the northern belt, but usually more crystalline and more closely folded. These, too, are cut by granites and other intrusives. Conditions are not so favorable for artesian water in the central and the coast belts as they are in the northern belt; nevertheless, in some areas within them, where the rocks are less highly tilted than elsewhere, or where they are much fissured, artesian waters have been developed. Springs, moreover, abound and a few drilled wells deliver water at the surface.

Upon the rocks of all three belts the glaciers that once covered the entire State deposited clay, sand, gravel, and a mixture of clay and bowlders. The latter constitutes the till, which covers all the older rocks as a blanket, varying in thickness from a few inches to many feet. The clay, sand, and gravel form terraces, hills, and ridges that run in gently sinuous lines for long distances over hill and valley, following, in the main, the directions of the principal drainage lines. In these deposits the various components are often interstratified, furnishing ideal conditions for successful shallow wells. Most of these wells obtain water either from the sand and gravel layers interleaved between the clay beds or from the rock surface underlying all the sediments.

The only remaining rocks that are at all widely spread in Maine are the beds of fossiliferous marine clays, which extend far inland up the river valleys and into lowlands where the elevation is not more than 230 feet above sea level. Over these clays are layers of river sand, deposited at a time when the streams were being fed by the melting glaciers. At the base of this sand, where it lies upon the clay, there is usually a constant sheet of water moving slowly riverward. This furnishes an unfailing source of supply to wells situated near the river banks, but unfortunately the water is often contaminated with impurities of various kinds.

WATER SUPPLY.

With the exception of Florida, Maine is the least densely populated of all the Eastern States. Because of this low density (23.2 per square mile) and its abundance of lakes and streams, its people have felt little necessity for seeking sources of water supply below the surface. Consequently, the underground waters of the State have been, on the whole, but slightly utilized, except in certain restricted areas, where, for one reason or another, the surface waters are not suitable for domestic or manufacturing purposes.

Until very recently the rivers and lakes have afforded excellent water for nearly all purposes. With the increase in the number of factories established on the main waterways for the advantages resulting from the possession of cheap water power, the rivers have become less and less valuable as sources of water supply, partly because of the waste products poured into them from the factories and partly because of the increased amount of sewage which they must carry in consequence of the growth of the manufacturing communities on their banks.

The drift of the population toward centers is well shown by the census of 1900. The number of cities and villages separately enumerated in this year was 43, as against 25 in 1890, and their population was 258,431, as against 184,821, or 37.2 per cent of the total population in 1900, as against 28 per cent in 1890.

The natural result of the two tendencies above mentioned has been to pollute the principal water courses, with the consequent result that communities drawing their public supplies from streams are beginning to complain of the quality of the water furnished them and are turning toward the lakes for relief.

Along the coast strip, where the larger rivers are tidal, communities are dependent upon lakes and small brooks for their public supply. On the islands the principal sources of drinkable water are springs and drilled wells, but since there are only a few island settlements of any considerable size the question of large public supplies is not of great moment.

Within the interior of the State village communities that are not situated near large lakes or spring-fed brooks have often taken advantage of the numerous good springs that abound everywhere and spring water has been piped through the settlements.

PUBLIC SUPPLIES.

The aggregate population furnished by water corporations from the three principal sources above mentioned is about 285,000, or about 40 per cent of the entire population of the State. Of this number about 152,000 obtain public water from lakes, 122,000 from rivers, and 14,000 from springs. In addition there is one community (Castine, population about 900) that draws its supply from four drilled wells.

RIVERS.

The communities at present obtaining their public supply from rivers and brooks are as follows:

Preliminary list of communities drawing upon streams as the sources of their public water supply.

Place.	County.	Source of supply.
Augusta	Kennebec	Kennebec River.
Bangor	Penobscot	Penobscot River.
Belfast	Waldo	Little River or Coles Brook.
Bethel	Oxford	Chapman Brook.
Benton	Kennebec	Messalonskee River.
Biddeford	York	Saco River.
Brewer	Penobscot	Penobscot River.
Calais	Washington	St. Croix River.
Caribou	Aroostook	Aroostook River.
Dover	Piscataquis	Piscataquis River.
Ellsworth	Hancock	Branch Pond Stream.
Ellsworth Falls	do	Do.
Fairfield	Somerset	Messalonskee River.
Freeport	Cumberland	Brook.
Fryeburg	Oxford	White Lot Brook.
Gardiner	Kennebec	Cobossecontee Stream.
Oldtown	Penobscot	Penobscot River.
Houlton	Aroostook	Moose Brook.
Kingfield	Franklin	Brook flowing into Tuffs Pond.
Milltown	Washington	St. Croix River.
Old Orchard	York	Saco River.
Pittsfield	Somerset	Sebasticook River.
Presque Isle	Aroostook	Kennedy Brook.
Richmond	Sagadahoc	Kennebec River.
Rumford Falls	Oxford	Androscoggin River.
Saco	York	Saco River.
Somerville	Lincoln	Sheepscot River.
Sorrento	Hancock	Piscataquis River.
South Berwick	York	Two Brooks.
Van Buren	Aroostook	St. John River and Violette Brook.
Waterville	Kennebec	Messalonskee River.

LAKES.

The list below is an enumeration of the communities utilizing lakes as their sources of supply.

Preliminary list of communities utilizing lakes as sources of water supply.

Place.	County.	Source of supply.
Auburn	Androscoggin	Lake Auburn or Wilton Pond.
Bar Harbor	Hancock	Eagle Lake.
Bath	Sagadahoc	Lake Nequassetto.
Bath (emergency)	do	120 driven wells.
Belgrade	Kennebec	Belgrade Lake.
Boothbay Harbor	Lincoln	Adams Pond.
Brunswick	Cumberland	
Camden	Knox	Mirror or Oyster River Lake.
Gorham	Cumberland	Sebago Lake.
Kittery	York	Folly Pond.
Lewiston	Androscoggin	Lake Auburn.
Livermore Falls	do	
Newport	Penobscot	Pillsbury Pond.
Norway	Oxford	Norway or Great Pennesseewassee Lake.
Oakland	Kennebec	Messalonskee Lake.
Phillips	Franklin	Mount Blue Pond.
Portland	Cumberland	Sebago Lake.
Rockland	Knox	Mirror or Oyster River Lake.
Rockland (auxiliary)	do	Lake Chicawanstin.
Rockport	do	Mirror or Oyster River Lake.
Seal Harbor	Hancock	Jordan's Pond.
South Portland	Cumberland	Sebago Lake.
South Paris	Oxford	Norway Lake.
Southwest Harbor	Hancock	Long Pond.
Thomaston	Knox	Mirror or Oyster River Lake.
Westbrook	Cumberland	Sebago Lake.
Wilton	Franklin	
Woolwich	Sagadahoc	Lake Nequassetto.
York	York	Chase's Lake.
York Corner	do	Do.

SPRINGS.

In the communities named below springs furnish nearly all the water used. In all cases this is carried by pipes either directly from the springs or from reservoirs into which the spring water is pumped.

Preliminary list of communities obtaining their public supply from springs.

Place.	County.	Remarks.
Addison	Washington	
Appleton	Knox	
Bingham	Somerset	2 springs fill 1½-inch and 6-inch pipes.
Brownville	Piscataquis	3 springs; piped to hotel and private houses.
Cherryfield	Washington	
Fort Fairfield	Aroostook	
Guilford	Piscataquis	Supplies 30 families.
Hallowell	Kennebec	
Harrington	Washington	
Lisbon Falls	Androscoggin	
Lubec	Washington	350,000 gallons a day. Temperature, 42°.
Millbridge	do	Fills 2-inch pipe. Temperature, 40°.
Monson	Piscataquis	Supplies 30 families.
North Waterboro	York	
Paris Hill	Oxford	From 10,000 to 30,000 gallons a day.
Peru	do	
Sanford	York	Fills ⅛-inch and ¾-inch pipes.
Sangerville	Piscataquis	
Searsmont	Waldo	
Searsport	do	
Skowhegan	Somerset	500,000 gallons a day.
Springvale	York	100 gallons a minute.
Stratton	Franklin	
Union	Knox	
Winterport	Waldo	125,000 gallons a day.
Yarmouth	Cumberland	120,000 gallons a day. Temperature, 49°.
Yarmouthville	do	

DRILLED WELLS.

The village of Castine is furnished with water for domestic and fire purposes by four drilled wells, of which three, situated at an elevation of 130 feet, are now used. In these the water was struck at a depth of 62½ feet, or 67½ feet above mean high-water mark. It rises naturally within 25 feet of the surface and is pumped to the surface with the aid of a windmill. These wells yield 40,000 gallons daily.

A fourth well, 675 feet deep, is located at an elevation of 217 feet. Water was struck in this well at a depth of 620 feet. It apparently came from fissures in the rock. The water level in this well is only 27 feet below the surface—i. e., it is 127½ feet higher than the level in the lower wells and 190 feet above sea level. All the wells are situated on the backbone of a small peninsula that extends into Penobscot Bay. This peninsula is only 2 miles long and 1 mile wide, and is joined to the mainland by a narrow isthmus which has been crossed by a canal. The deepest well, whose water rises 190 feet above sea level, is only half a mile from the shore of the bay.

PRIVATE SUPPLIES.

The farming communities in Maine, as elsewhere in the Eastern States, consist of isolated families or very small groups of families in villages that are not large enough to warrant the wholesale distribution of water. Water can not be conveyed to them economically from long distances, hence their supplies must come from near-by sources, which are available almost everywhere immediately beneath the surface. These underground sources are tapped by dug and by drilled wells, or by the natural fissures through which springs issue.

DUG, DRIVEN, AND BORED WELLS.

The soil covering of Maine is largely glacial in origin. The drift which covers the hard rocks is of considerable thickness over most of the State, and from its nature it affords many reservoirs for the storage of ground water. Where gravels and sands are intercalated between clay beds these furnish abundant water. The depth of the layers from which the water is derived varies widely even in the same neighborhood, because the coarse-grained beds are not of great horizontal extent, and neighboring wells, therefore, must often obtain their water from different layers. In those places where the drift covering is thin the rock under the drift is blasted into, and in this way a shallow basin is made, into which water seeps from the basal layers of the overlying drift and from the crevices opened up in the rock.

In the valleys of many of the rivers are deposits of clay, which were either laid down by the rivers themselves or by bays of the ocean which formerly extended inland up the river valleys. Between the successive beds of clay are often thin layers of water that are continuously flowing riverward as broad sheets. Where these are intercepted by wells an abundant and constant supply of water is obtained. Wells of this class possess, in a measure, artesian characters. The water often rises above its immediate source, and its height is only slightly affected by droughts. On the other hand, the beneficial effect of sand filtration upon the water is lacking, and consequently these wells are more apt to become polluted than those that obtain their water by tapping supplies in sand or gravel. A rapid examination of the records of the State board of health shows that the greater proportion of the polluted wells investigated by the board are those which obtain their water from between clay layers; whereas, on the other hand, the wells obtaining their supply from the sand beds in the drift usually furnish good water, although they may be situated in the midst of farm buildings that have occupied the land for periods of fifty or seventy-five years.

DRILLED WELLS.

Because of the abundance of streams, lakes, and springs in the State, and the ease with which the underground water in the glacial drift may be reached by dug, driven, and bored wells, the use of drilled wells is not common. There are a few in the interior counties where the supply of surface water is not constant and where the drift is thin and dug wells are likely to fluctuate with variations in the amount of rainfall, but by far the greater portion of the deep wells are situated either on the islands off the cost or in a narrow strip on the mainland bordering the shore. This shore strip is almost insular in character. Deep inlets extend back into the land, separating it into narrow tongues that are almost surrounded by salt water. Moreover, the drift covering is usually thin, and in this belt, as on the islands, the collecting areas are small and the capacity of the drift for storage is small.

Records of the rocks drilled through have been kept for very few of the wells. This fact, together with the fact that the geology of the State is practically unknown, makes it impracticable to work out at present the limits of artesian basins. From the scanty data at hand, however, it appears probable that at least one basin exists in the northeastern part of the State, in the eastern portion of Aroostook County, and another in the west-central part, surrounding Moosehead Lake.

At Greenville, at the mouth of Moosehead Lake, are two wells that flow. These two and a few others in the coast belt are the only ones that furnish water at the surface. In the great majority of the wells, however, the water is forced upward by natural pressure some distance above its source.

Of the 448 drilled wells of which reports have been received, 134 are 100 feet deep or over. Of these there are 2 over 500 feet deep, 7 between 300 and 400 feet, and 25 between 200 and 300 feet.

SPRINGS.

Throughout the interior of the State springs are frequently used as sources of water supply when they are situated at a greater elevation than the buildings to be furnished with water. Often several families combine and have the water of the larger springs distributed through their dwellings by pipes. Occasionally the water is raised by windmills, but usually it is distributed by gravity alone. In those portions of the State where the well water is hard, springs are more generally utilized than in those portions where the well water is soft. In a few instances where the quality of the water in the streams near by is poor, springs supply water for manufacturing establishments.

Very important springs, which are of great economic value to the State, are those which may be denominated commercial springs. This group includes those springs whose waters are sold by measure, i. e., in small parcels. Of this class there are two subclasses. In the first are included springs that furnish water to consumers in their vicinity

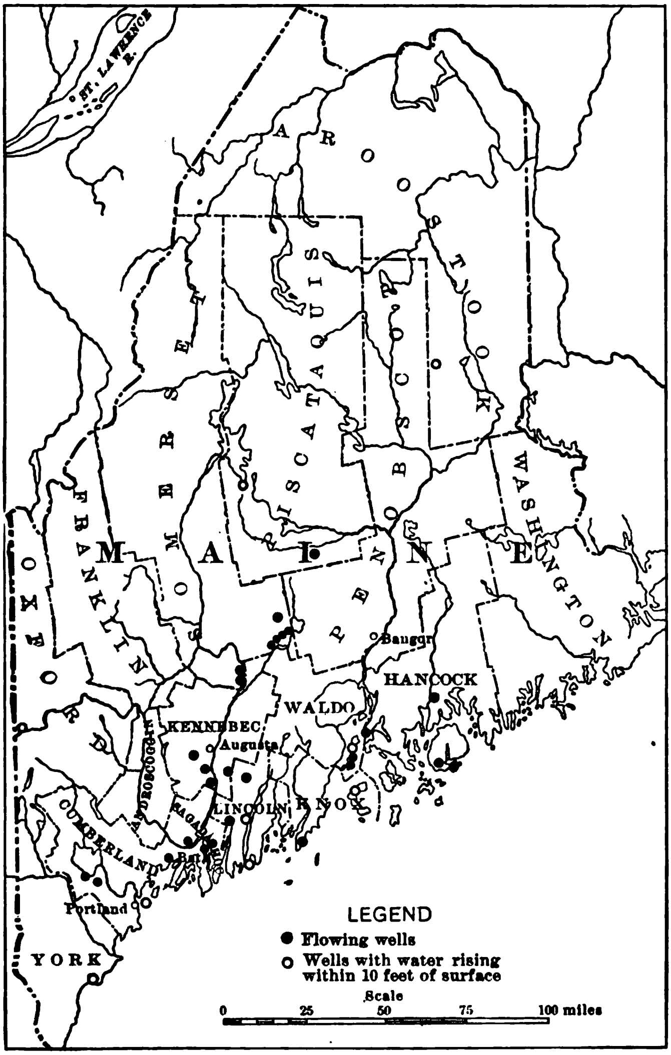

FIG. 15.—Location of flowing or nearly flowing wells of Maine.

at regular intervals, to be used as table water. In this group there are at present known to be 25 springs, from which 486,000 gallons are sold at a cost to the consumers of $29,782. A list of these, with analyses of their waters, is given in the table on pages 51 to 53. The second subclass includes springs whose waters are bottled and shipped to distant points. The mineral springs whose waters are supposed to possess medicinal properties are included here, and also certain other springs whose water is exceptionally pure. The quantity of water shipped from these in 1902 was 355,865 gallons, valued at $71,415. This amount does not include the sales of water from Poland Spring, the proprietors of which decline to make any statement as to the quantity or value of the water supplied by them to consumers. It is known, however, that the aggregate value of the water shipped from this spring is greater than that of all the other springs in the State. The springs in this group number 22. (See table on page 54.)

Preliminary list of springs furnishing water sold in their vicinity.

Name.	Location.	County.	Flow per minute, in gallons.	Temperature.	Remarks.
				°*F.*	
1. Rocky Hill	1¼ miles north of Fairfield	Somerset	3		Sold in Waterville and Fairfield.
2. Arctic	1½ miles north of Bangor	Penobscot	8	44	Sold in Bangor. Hardness, 6 per 100,000.
3. Puritan	3 miles west of Pine Point	York	2½	47	Sold in York and vicinity.
4. Granite	Long Island, Casco Bay	Cumberland		40	Piped into hotel.
5. Seavey's Purity	1 mile southwest of West Scarboro	do	3	40	Hardness, 2,128 per 100,000.
6. Forest	6 miles west of Gardiner	Kennebec	2	42	Sold in Gardiner and neighboring towns.
7. Do	do	do	2	42	
8. Do	do	do	2	42	
9. Paradise	1¼ miles east of Brunswick	Cumberland	8	43–45	Sold in Brunswick.
10. Cliff	¼ mile west of East Turner	Androscoggin	1½	Warm.	Sold in Lewiston.
11. Ticonic Mineral	2 miles northeast of Waterville	Kennebec	5½		Sold in Waterville. Hardness, 15.5 per 100,000. Sulphureted.
12. Seal Rock	1 mile east of Saco	York	9½	Cold.	Sold in Biddeford and Saco.
13. Mount Desert	1 mile north of Northeast Harbor	Hancock	12	42	Sold in vicinity.
14. Littlefield's	½ mile west of Gardiner	Kennebec			Sold in Gardiner and vicinity.
15. Morse's	6 miles southwest of Gardiner	do			Do.
16. Pine Grove	5 miles southeast of Pittsfield	Waldo	60–100	48	Sold in Pittsfield and vicinity.
17. Chapman's	¼ mile north of East Orrington	Penobscot	Large.	Cold.	Sold in Brewer.
18. Lowrie's	2 miles northeast of Eastbrook	Hancock	10	40	Used in hotel.

Preliminary list of springs furnishing water sold in their vicinity—Continued.

Name.	Location.	County.	Flow per minute, in gallons.	Temperature.	Remarks.
				°F.	
19. Jones's	½ mile west of Norway	Oxford	½	Very cold.	Sold in Norway.
20. Pure Water	1½ miles north of Waterville	Kennebec			Sold in Waterville. Hardness, 4.15 per 100,000. Carbonated.
21. Vienna Sparkling	¼ mile from Vienna	do	2		
22. Skid Hill	¾ mile east of Poland	Androscoggin	30		Used in hotel.
23. Keystone Mineral	East Poland	do	5		
24. Hallowell	⅛ mile southwest of Togus	Kennebec			Supplies Soldiers' Home.
25. Sylvan	Durham	Androscoggin	1	40	

Analyses of water of springs listed above.

[Parts per million.]

	$CaCO_3$	$MgCO_3$	$FeCO_3$	Na_2CO_3	$CaSO_4$	$MgSO_4$	Na_2SO_4	K_2SO_4	NaCl	Fe_2O_3	Al_2O_3	SiO_2	Org.	Total.	Analyst.
1[a]	24.1	12.7		1.5	3.4			0.9	4.0			11.0	5.4	63.0	F. C. Robinson.
6	55.4	5.6		[b]2.4			8.0	6.2	4.8	trace.		14.2	3.0	99.6	Do.
7	21.6	5.3		[b]4.0			1.3	1.7	4.5			13.7	3.3	55.4	Do.
8	5.4	1.6		3.0			.5	1.3	3.5			9.5	3.0	27.8	Do.
9	1.7	1.0	0.2	4.2		1.0			[c]2.6			6.6	.3	17.7	Do.
10	6.7	4.8				4.4			6.3	1.9		5.6		29.7	L. G. Jordan.
11[d]										trace.		10.6		184.7	S. K. Hitchings.

18	4.0	1.7	......	......	......	......	2.6	......	4.4	.2	7.3	......	20.3	J. W. Baird.
21 *a*	32.0	5.4	......	trace.	......	......	......	4.3	.3	.9	8.2	.00	51.2	C. F. Chandler.
21 *b*	10.6	3.3	......	12.2	......	......	......	1.0	.2	trace.	15.1	.00	42.4	S. D. Hayes.
23	......	11.1	7.7	5.1	......	......	4.3		4.3	4.3	14.5	trace.	......	R. C. Stanley.
24	10.0	2.9	......	......	......	......	2.8	......	[e]12.0	....	15.0	6.3	49.5	Unknown.
25	3.8	2.4	......	......	......	3.6	......	2.0	9.8	2.2	5.1	......	28.9	L. G. Jordan.

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[a] The figures to the left correspond to those preceding the names of the springs in list of springs.

[b] Traces Li_2CO_3.

[c] Including KCl.

[d] Other compounds determined in this water, in parts per million, are CaO, 59.5; MgO, 16.4; FeO, 7.4; Na_2O, 26; K_2O, 6; Cl, 5.6; CO_2., 51; SO_4, 2.2; P_2O_5, trace.

[e] Including KCl, 0.6.

Preliminary list of springs furnishing water that is shipped.

Name.	Location.	County.	Flow per minute (in gallons).	Temperature.	Remarks.
				° *F.*	
1. Mount Oxford	2 miles north of Buckfield	Oxford	4	40	
2. Carrabassett	9 miles north of Kingfield	Franklin	10	42	
3. Ishka	1 mile south of West Hancock	Hancock	4	Cool.	Hardness, 41.5 per 1,000,000.
4. Pine	2½ miles southeast of Topsham	Sagadahoc	5	45	
5. Auburn Diamond	1 mile northwest of Auburn	Androscoggin	15	41	
6. Glenwood	2 miles north of St. Albans	Somerset	60	48	
7. Pownal	1½ miles north of West Pownal	Cumberland		42	
8. Bluehill	2½ miles northwest of Bluehill	Hancock	6	45	Hard, alkaline, chalybeate.
9. Bluehill	do	do	5	55	Soft.
10. Mount Hartford Cold	4 miles north of Buckfield	Oxford	3½	38	Lithia.
11. Hill's Mineral	1 mile east of Saco	York	1	42	
12. Zircon Moon Tide	Zircon	Oxford	14	40	
13. Underwood	6¾ miles northeast of Portland	Cumberland	140	46	
14. Boothbay Medicinal	East Boothbay	Lincoln	2½		Chalybeate; carbonated.
15. Windsor Mineral	2½ miles northeast of Lewiston	Androscoggin	10	48	Chalybeate.
16. Auburn	5 miles north of Auburn	do	25	49	
17. Addison Mineral	1½ miles east of Addison	Washington	30	35	Chalybeate; carbonated.
18. Samoset Mineral	½ mile west of Nobleboro	Lincoln	½	Cold.	Carbonated; sulphureted.
19. Highland Mineral	¾ mile east of Poland	Androscoggin	2	45	Carbonated.
20. Poland	South Poland	do	8		Alkaline.
21. Knowlton's Soda	2½ miles south of Strong	Franklin	8		Do.
22. Summit	Harrison	Cumberland	38	46	

Analyses of water from springs in preceding list.

[Parts per million.]

	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	Na_2CO_3.	$CaSO_4$.	$MgSO_4$.	K_2SO_4.	NaCl.	Fe_2O_3.	Al_2O_3.	SiO_2.	Organic and volatile.	Total.	Analyst.
1 [a]...........	16.0	1.0	......	....	2.0	......	....	4.0	3.0	....	8.0	....	34.0	E. E. Calder.
2...........	10.56	5.98	......	([b])	5.78	......	....	2.72	.60	....	11.50	....	....	S. P. Sharples.
2...........	18.0	5.4	......	....	3.6	14.4	3.6	7.2	5.4	....	14.4	....	72.0	La Bua.
3...........	1.688	1.717	......	....	1.894	......	....	[c] 3.774	.242		6.386	....	18.757	H. Carmichael.
4...........	2.72	.11	0.69	1.04	....	......	[d] .34	[c] 3.71	....		4.64	....	13.25	F. C. Robinson.
5...........	....	23.1	13.8	[e] 4.3	....	......	[f] 19.7	4.3	10.3	3.4		....	78.9	R. C. Stanley.
6...........	25.0	35.0	......	....	....	......	....	....	2.0	2.0	3.0	....	67.02	S. S. Bradford.
7...........	5.7	.4	.7	[g] 1.5	....	......	[d] 1.3	2.7	....	....	7.0	1.7	19.5	F. C. Robinson.
8...........	25.16	6.09	6.62	....	5.61	......	[d] 5.33	[h] 5.0	....	1.89	20.56	([i])	78.61	W. P. Mason.
9...........	5.59	3.11	.52	....	13.09	......	....	4.12	....	8.38	12.44	([j])	48.77	Do.
10...........	8.0	2.5	.8	4.3	....	......	[k] 1.4	1.8	....	[l] .2	[m] 11.0	([n])	30.0	J. W. Mallett.
12...........	1.6	2.3	......	6.0	5.4	......	....	1.3	.12		9.0	....	25.8	S. P. Sharples.
13...........	8.2	2.5	......	....	....	......	2.0	14.7	....		8.6	....	36.0	F. L. Bartlett.
14...........	[o] 57.0	[o] 17.3	[o] 46.7	....	....	......	34.0	32.2	....	Trace.	11.0	([p])	198.2	Do.
15...........	....	16.1	14.4	....	....	......	[f] 24.9	8.6	....	22.3		....	86.3	R. C. Stanley.

[a] The figures to the left correspond to those preceding the names of springs in list above.

[b] Also K_2CO_3=1.5.

[c] Including KCl.

[d] Na_2SO_4.

[e] Including K_2CO_3.

[f] Including Na_2SO_4.

[g] Also K_2CO_3=.3.

[h] Also KCl=9.9.

[i] Also $NaNO_3$=.91 and $MnCO_3$=.45.

[j] Also $NaNO_3$=1.52.

[k] Also Na_2SO_4=4.6.

[l] Al $(OH)_3$.

[m] Metasilicic acid.

[n] Also $MnCO_3$=.0058 .1; $SrCO_3$=.1; $RbCO_3$=tr.; Li_2CO_3=.05; $NaNO_3$=1.2; Na_3PO_4=.03.

[o] Bicarbonates.

[p] $FeSO_4$=18.9.

Analyses of water from springs in preceding list—Continued.

	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	Na_2CO_3.	$CaSO_4$.	$MgSO_4$.	K_2SO_4.	NaCl.	Fe_2O_3.	Al_2O_3.	SiO_2.	Organic and volatile.	Total.	Analyst.
16	[a]7.5	[a]5.1	......	[a]20.5	......	......	3.1	4.4	Trace.	Trace.	24.1	......	64.7	S. D. Hayes.
17	[a]45.2	[a]19.2	[a]28.2	[a]7.6	9.0	......	[b]10.3	15.2	......	Trace.	Trace.	......	134.7	Do.
18	18.6	6.7	39.0	277.0	52.5	......	......	18.6	Trace.	......	12.5	Trace.	424.9	H. C. Carmichael.
19	37.4	9.3	......	......	......	......	17.7	8.1	......	......	11.2	......	83.7	F. L. Bartlett.
20	21.1	9.3	......	2.3	......	......	2.7	4.6	Trace.	Trace.	19.2	4.0	63.2	C. F. Chandler.
21	5.5	2.3	......	6.4	......	......	7.7	4.4	Trace.	Trace.	16.3	......	42.6	
22	17.0	4.2	......	[c]24.0	......	......	......	3.0	Trace.	Trace.	16.7	4.1	......	F. L. Bartlett.

[a] Bicarbonates.

[b] Including Na_2SO_4=4.5.

[c] Including K_2CO_3.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 13–16.

Maine [well and spring records], by W. S. Bayley: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, 1904, pp. 26–55.

NEW HAMPSHIRE.[a]

By M. L. FULLER.

TOPOGRAPHY.

Taken as a whole New Hampshire is more rugged than any other New England State. Although the mountains are lacking in the definite trend which characterizes the Green Mountain and Berkshire Hill ranges, they comprise, nevertheless, the highest and most rugged peaks of the eastern section of the country north of North Carolina. The highest land is in the western and northern parts of the State, culminating in the White Mountains of the north-central portion, where Mount Washington and several other peaks reach elevations of 5,000 to 6,000 feet or over. The lowest area within the State is in the southeastern portion, where much of the land is less than 500 feet above sea level, considerable tracts lie between 500 and 1,000 feet, and a few hills and ridges above 1,000 feet.

In general the hills and mountains present smooth and rounded outlines, while the valleys are generally wide, with gentle or moderate slopes. In addition to the rock hills, there are, in the southern third of the State, a large number of smooth, lenticular hills, 100 feet or more in elevation above their base, composed of deposits formed by the glaciers when they occupied the region. They are known as drumlins.

GEOLOGY.

Over the greater part of the State the rocks are of the crystalline type, and include granites, gneisses, etc., but along the western border, and also along a broken belt extending from the southwestern portion of the State northeastward into Maine, in the vicinity of Rochester, there are extensive outcrops of slates, quartzites, schists, etc., with occasional small areas of limestone. The rocks of all types are generally characterized either by bedding or lamination planes, and are frequently much broken by joints.

Like other New England States, New Hampshire is covered with surface deposits of unconsolidated material laid down by the ice sheet or its associated drainage ways. This surface material or drift is not of uniform distribution, being in general of much greater thickness in the southern portion of the State than in the northern. Neither is the drift of uniform thickness in the same general region, the crests and sides of the mountains and many of the higher hills being thinly coated with or even nearly free from glacial materials. In the valleys and on the lowlands, however, the drift deposits reach a considerable thickness and afford the most important source of water in the State.

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[a] The portions of the present descriptions relating to wells and springs are based on data collected by Mr. J. M. Boutwell.

Of the types of drift the stratified deposits along the present stream channels are the most important. The sands and gravels along the Connecticut, Merrimac, Pemigewasset, Ashuelot, Contoocook, Saco, and Great Ossipee rivers are of considerable importance. Many small areas and a few large ones are covered by deposits laid down in glacial lakes at a time when the retreating ice margin blocked the northward-flowing streams. Extensive stratified deposits also occur along the Atlantic coast in the southeastern portion of the State. Outside of the areas of stratified materials of the river bottoms, glacial lake basins, and along the coast, the surface is generally covered with a bowlder clay, or hard pan, known as till. In general it is very thin, but becomes of considerable thickness in the lenticular hills, known as drumlins, in the southern third of the State.

UNDERGROUND WATERS.

WELLS.

The wells may be grouped into two classes: (1) Those in the drift and (2) those entering the rock. Of the wells in the drift, those in the compact and more or less clayey till or hard pan yield the least satisfactory supplies both as regards quantity and quality. In the stratified drift, especially in the sands and gravels of the valleys and basins mentioned above, the supplies are generally of good quality and ample in volume. In the more densely populated portions of the State, especially near the coast, the shallow drift waters are sometimes liable to pollution, but satisfactory supplies can usually be obtained at almost any point where the stratified drift occurs.

Wells are in general drilled into the rock only when satisfactory supplies can not be obtained from the drift. The rocks over a large part of the area are crystalline and dense and do not present ideal conditions for water storage, so that the value of a rock well must always be in doubt until it is completed. As already pointed out, the crystalline rocks are generally marked by lamination planes and are cut by joints, while the slates, quartzites, limestones, and other stratified rocks are characterized likewise by joints and also in many instances by rather definite bedding planes. The general effect of all of these features is to allow the water to penetrate into the interior of the rock, and most deep rock wells obtain moderate supplies, but irregularities in the occurrence of joints and other planes render the results of drilling very uncertain.

Many wells from 200 to 1,300 feet deep have been drilled in the State, nearly every county being represented. The majority of these have found water, although a few of the deeper wells have been failures. The supplies in some of these wells are so great as to warrant the installation of steam pumps for raising the water. The deep wells are used mainly in the various manufacturing industries and by the larger hotels.

The waters of the drift are generally soft and relatively free from mineral matter, but those obtained by the deeper rock wells are frequently hard and charged with mineral matter, especially iron.

SPRINGS.

As in all rugged regions, springs abound in the hilly portions of New Hampshire. Over a large portion of the western and northern part of the State there is hardly a farm that is without one or more available springs. In these regions springs are the leading source of domestic supplies, and at a number of places, as at Dover, Gorham, North Stafford, Nashua, Bennington, and elsewhere, springs constitute a principal or partial source of public supply. Spring waters are also frequently used in dairy and other similar industries at many points throughout the State.

Besides the uses outlined above many of the spring waters of New Hampshire are placed on the market for medicinal or table use. In 1902, eight springs reported sales amounting to 629,500 gallons, with a value of $185,995,[a] viz:

Amherst Mineral Spring, Amherst, Hillsboro County.
Granite State Spring, Plaistow, Rockingham County.
Hale Spring, Plaistow, Rockingham County.
Lafayette Spring, West Derry, Rockingham County.
Londonderry Lithia Spring, Londonderry, Rockingham County.
Mount Madison, formerly Gorham Mineral Spring, Gorham, Coos County.
Pack Monadnock Lithia Spring, Temple, Hillsboro County.
Toof's Artesian Well, Concord, Merrimac County.

In addition to the above springs there are probably many local springs which supply water for family use on a small scale in the cities. A number of resorts have also been established at springs.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 17-18.

New Hampshire [well and spring records], by J. M. Boutwell: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, 1904, pp. 56-72.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

VERMONT.

By G. H. Perkins.

GENERAL CONDITIONS.

Vermont is 157 miles long from north to south and, on the average, about 58 miles wide from east to west. The Green Mountain Range, which divides the State into nearly equal east and west portions, forms a watershed from which most of the streams flow either east into the Connecticut or west into Lake Champlain. As the mountains and foothills occupy a large portion of the State there is little level ground, the surface being mostly uneven—mountain, hill, or valley. The mean rainfall over the State is not far from 39 inches. Probably no State is more abundantly watered, for in most of the towns springs are numerous and unfailing, and these are supplemented elsewhere by wells and streams.

The unaltered stratified rocks of Vermont are found mostly in the Champlain Valley, where the Cambrian sandstone, Beekmantown sandstones and limestones, Chazy, Trenton, and sometimes Black River limestone and Utica shales form a narrow border along the western part of the State. East of these unchanged beds the rocks are largely crystalline and metamorphic, consisting of granite, gneiss, schist, and slate. The whole State is covered with glacial deposits, composed of gravels, clays, and sands.

WATER SUPPLY.

Public supplies.—Because of the abundance of springs and the consequent ease and cheapness with which a public water system can be established in many towns, such supply is often found where it would scarcely be expected. At least 65 towns and villages have a more or less complete public supply. Some of these are owned by the towns, many by corporations or individuals. In a number of towns there are several systems; for example, Barre has at present a system owned by the city, which supplies 1,200 families, and at least 5 smaller supplies, which are used by from 6 to 250 families each. Montpelier is still more lavishly provided, there being the city supply, which furnishes by far the greater number of the residents, and, in addition, more than twelve other sources which supply from 2 to 50 or more families. In 1898 a State laboratory of hygiene was established, and as water used for drinking can, under certain regulations, be analyzed here free of charge, most of the water used in the larger towns is frequently examined chemically. In the following table are given the sources of supply of most of the important cities and towns of the State:

Sources of water suppty of Vermont towns.

County.	Town.	Source of supply.	Ownership.
Addison	Middlebury	Springs	Town.
Do	Vergennes	Otter Creek	City.
Bennington	Arlington	Spring	Arlington Water Company.
Do	Manchester	Equinox Springs S. M. Orvis's springs	Town.
Caledonia	East Barnet	Springs	Town water company.
Essex	Island Pond	do	Island Pond Water Company.
Do	Lunenburg	Three large springs	
Franklin	Richford	Springs	Town.
Do	St. Albans	Reservoir (4 miles from town).	Do.
Lamoille	Hydepark	Springs	Private.
Do	Jeffersonville	do	Town.
Do	Johnson	do	Waterman & Welch.
Do	do	do	Water company (J. A. Pearl, agent).
Do	Stowe	do	C. E. and F. O. Burt.
Orange	Bradford	A series of springs	Town.
Do	North Thetford	Springs	Union and North Thetford water companies.
Do	do	Union and North Thetford water companies.	Independent farmers.
Orleans	Derbyline	Springs	Town.
Do	Glover	do	Private.
Do	North Troy	do	Two companies.
Rutland	Brandon	Hitchcock Pond (6 miles north).	Town.
Do	Center Rutland	Springs	Do.
Do	Danby	do	Do.
Do	Pittsford	Large spring	Do.
Do	Poultney	Crystal Lake, Hampton, N. Y.	Do.
Do	Proctor	Springs	Do.
Do	Rutland	Mendon brooks	Do.

Sources of water supply of Vermont towns—Continued.

County.	Town.	Source of supply.	Ownership.
Washington	Barre	Several companies	Water company.
Do	do	Springs	Harvey Hersey.
Do	do	Brooks	Private and city.
Do	do	Spring	Barre Spring Company.
Do	Marshfield	Springs	Batchelder Water Company.
Do	Middlesex	do	Private owners.
Do	Montpelier	Berlin ponds (two)	City.
Do	Northfield	Two public systems	Private.
Do	Plainfield	Springs	Village.
Do	Roxbury	do	J. W. Howe and G. A. Tilden.
Do	Waterbury	Brooks and springs collected.	Town.
Do	Waterbury Center	Springs	Hopkins & Company.
Windham	Bellows Falls	Minard's pond	Town.
Do	Jamaica	Fifteen springs	Do.
Windsor	Chester	Stream	Chester Water Company.
Do	Hartford	Springs	A. L. Peace.
Do	Ludlow	do	Town.
Do	Norwich	do	Do.
Do	Rochester	do	Do.
Do	Springfield	do	Do.
Do	White River Junction.	do	Do.
Do	Wilder	Three springs	Olcott Water Company.
Do	Windsor	Springs	Town.

Common springs.—As has been indicated, springs are abundant over a large part of the State. Of the 248 towns reporting, not less than 190 are said to be wholly or in large part supplied from springs. Many of these springs are large and constant in flow and temperature, the latter being often as low as 38° F., even in midsummer, and many show throughout the year a temperature varying but little from 45° F.

As there is little or no soluble matter in the rocks in most parts of the State, the spring water is usually pure and soft.

The abundance of springs is shown in the reports from single and not large farms, that within their limits there are 20, 30, or even 40 active springs. The water supply of most towns having a public water system is taken either from one large spring or from several which have been connected. Analyses of many of these springs could be given. Nearly all of them, however, simply show pure water with no organic and very little solid matter, and as Vermont is for the most part not thickly settled, there are few or no sources of contamination. As an example of what may be regarded as an average sample of Vermont spring water, the following is given. The sample was taken from a tap located at some distance from the reservoir supplied by springs. It is not the purest nor the worst.

Analysis of water from Johnson, Vt.

	Parts per million.		Parts per million.
Total solids	40.4	Nitrogen as nitrates	.100
Loss on ignition	3.2	Nitrogen as nitrites	None.
Fixed solids	37.2	Hardness	3.1
Free ammonia	.018	Turbidity	None.
Albuminoid ammonia	.07	Sediment	None.
Chlorine	.4	Color	None.

Mineral springs.—Mineral springs are found, though not in large number, in different parts of the State. Most commonly they are more or less sulphurous, but alkaline carbonated springs also occur. The chief resorts on account of the water are Alburg Springs, Highgate, Sheldon, Clarendon, Middleton, and Brunswick. The springs at South Hero, Chelsea, Concord, Wolcott, Newbury, and Warren are all of some repute. The Equinox Spring, at Manchester, is not mineral, but is simply a very fine spring of pure water. The water of some of the deep wells is so strongly magnesian as to properly come under the class of mineral waters.

The springs reporting shipments of water in 1902[a] are as follows:

Brunswick Mineral Spring, Brunswick, Essex County.
Clarendon Springs, Clarendon Springs, Rutland County.
Equinox Spring, Manchester, Bennington County.
Middletown Springs, Middletown Springs, Rutland County.
Missisquoi Mineral Springs, Sheldon, Franklin County.
Newfane or Vermont Mineral Spring, Putney, Windham County.

The amount shipped is stated as 89,100 gallons, with a value of $22,760.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

As examples of these mineral waters the following analyses are given:

Analyses of Vermont spring waters.

Clarendon Spring.	Parts per million.	Missisquoi Spring.	Parts per million.
Sodium chloride	2.5	Free carbonic acid	45.49
Potassium sulphate	2.0	Sodium chloride	.38
Calcium sulphate	.8	Calcium chloride	2.12
Calcium bicarbonate	182.2	Magnesium chloride	.60
Magnesium bicarbonate	36.7	Sodium sulphate	6.52
Magnesium chloride	1.1	Calcium sulphate	12.09
Iron bicarbonate	1.8	Aluminium sulphate	2.70
Silica	11.2	Magnesium sulphate	5.51
Alumina	.8	Sodium phosphate	.08
		Sodium bicarbonate	126.62
		Magnesium bicarbonate	72.19
		Manganous bicarbonate	1.40
		Ferrous bicarbonate	3.03
		Silica	12.25
		Crenic and apocrenic acid	Trace.
		Titanic acid	Trace.

Ordinary wells.—Wells of any sort are less common than they would be if springs did not afford a more convenient and better source of water. Underground water is everywhere and wells can be successfully dug in all parts of the State. Most of the wells thus far dug are not deep, ranging from 10 to 30 feet, and are usually wholly in the drift or other glacial deposits. Occasionally a well is carried down into the underlying rock, but not often.

The water of wells is usually reported as hard and almost always the amount of solids in well water is much greater than in spring water. In some parts of Vermont, as on Grand Isle, it has been found better to dig very large, though shallow wells. Some of these are 16 feet in diameter and 12 to 15 feet deep. In this way more water is procured than would be obtained by making a small well and going deeper.

Deep and artesian wells.—Wells of this class are found most commonly in the Champlain Valley and in the stratified rocks. The water is very often strongly impregnated with alkaline salts, especially of magnesia and lime, and is therefore very hard. Reports have been received from about 100 wells which are over 50 feet deep. This number, however, does not include nearly all there are in the State. The deepest well in the State is one which was bored for experimental purposes rather than water by Dr. W. S. Webb. It is 1,400 feet deep and gives no water, though only 300 feet from the lake shore. A well sunk not far from the shore of the lake by the Burlington Rendering

Company to a depth of 490 feet found no water. In both cases water had to be supplied from outside for the drilling.

Only a few of these wells flow, but in a few the water rises from 4 to 18 feet above the mouth of the well. In or near Burlington there are 16 wells bored to depths of from 130 to 496 feet. At least 5 of these are so strongly impregnated with lime and magnesia salts that they can not well be used for steam, since the precipitation of these salts fills the pipes. The water in these wells is clear and cold and is much liked for drinking. It has been found very beneficial in some cases of dyspepsia.

The character of the beds passed through by these wells was much the same, but the thickness of each bed varied greatly; that is, the first beds were glacial and the last were Cambrian or Lower Beekmantown, but in one well the glacial beds are only 20 feet thick, while in another they are over 200. In the slate region, which is Cambrian, there are more deep wells than in any other part of the State. Mr. J. P. Hoadley, who has bored more wells than anyone else in the State, tells me that he has bored over 50 in the town of Poultney alone. Probably no other town has so large a number. As has been noticed, most of the deep wells are near the western border of the State, in the towns bordering Lake Champlain. The usual cost of boring deep wells in this State is from $1 to $5 per foot.

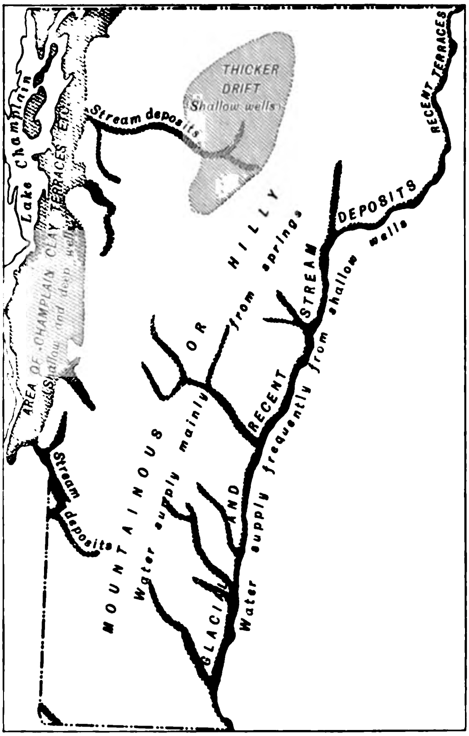
Lake Champlain
AREA OF CHAMPLAIN CLAY TERRACES ETC.
(Shallow and deep wells)
THICKER DRIFT
(Shallow wells)
Stream deposits
Stream deposits
RECENT TERRACES
MOUNTAINOUS OR HILLY
Water supply mainly from springs
GLACIAL AND RECENT STREAM DEPOSITS
Water supply frequently from shallow wells

FIG. 16.—Water-bearing drift deposits of Vermont.

Lakes and ponds.—Naturally many of those who live near Lake Champlain take water from it by windmill or, more rarely, by steam pump. The only town that takes its supply from the lake is Burlington, the largest place in the State. Here the water is pumped by steam to two large reservoirs, nearly 400 feet above the lake, from which it goes by gravity over the city.

An average analysis of the water of Lake Champlain taken from faucet is as follows:

Analysis of water of Lake Champlain.

	Parts per million.		Parts per million.
Total solids	74.1	Nitrates	0.128
Loss on ignition	18.0	Nitrites	.00
Fixed solids	56.1	Sediment	([a])
Free ammonia	.035	Turbidity	([a])
Albuminoid ammonia	.143	Hardness	4.3
Chlorine	.68		

[a] Very slight.

A few towns, as, for example, Brandon and Bellows Falls, get water from small lakes or ponds. Some of these ponds are directly fed by springs and are therefore very satisfactory as a source of supply.

Streams.—A few towns—Vergennes, Wells River, and some others—get water from adjacent streams. There seems to be more danger of contamination in this case, and the supply is therefore less satisfactory.

Cisterns.—Cisterns are not much used in this State, but there are some places in which the only other supply is from wells which give hard water, and in these places cistern water is used for drinking and laundry. The whole number of towns reporting cisterns in use is very small.

SUMMARY.

It will be seen from the foregoing statements that the questions which the necessity for wholesome and abundant water for domestic purposes raise in many parts of the country are not important in Vermont. Everywhere, except in a few places, water is abundant in quantity and excellent in quality. Many towns allow a large quantity of cool, clear, pure spring water to run to waste because there is no use for it. But the conditions under which this ample supply exists are extremely interesting and deserve extended study.

As has been noted, most of the wells and springs are located in the glacial deposits. These are often very thick. Some of the wells have gone through 200 feet or more of these deposits before reaching the underlying rock. For example, one of the four deep wells at Fort Ethan Allen was bored through 221 feet of sands and clays and then went over 150 feet into the ledge below. Few wells except those of considerable depth go into the rock. Most either stop in hardpan some distance above the rock or go just to the ledge, but rarely into it, and in those cases where, in the hope of getting more water, the rock has been entered, the result has not always been satisfactory, no increase in amount of water being gained. In some wells that have been carried a short distance into the rock more and better water has been obtained, but such cases are the exception. The above applies only to shallow wells. In the deep wells often the volume of water flowing has been increased by boring deeper. This is, however, by no means always true. In the reports of several deep wells we find that as much or more water was found at 200 feet as at 300 or more.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 18-21.

Vermont [well and spring records, town water supplies, and analyses], by G. H. Perkins: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, 1904, pp. 73-93.

Water resources of the Fort Ticonderoga quadrangle, Vermont and New York, by T. Nelson Dale: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1905, pp. 126-129.

Water resources of the Taconic quadrangle, New York, Massachusetts, and Vermont, by F. B. Taylor: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1905, pp. 130-133.

MASSACHUSETTS AND RHODE ISLAND.

By W. O. Crosby.

Since Rhode Island is half encircled by Massachusetts and presents no essentially distinctive topographic or geologic features, the two States may best be treated as a unit in a preliminary study of their underground waters.

GEOLOGY.

In a broad way Massachusetts and Rhode Island may be subdivided, according to the relief of the land, into a number of belts, each marked by its own characteristic geology and topography. The westernmost of these may be termed the Berkshire Hills. These are a series of high mountainous ridges lying in the extreme western part of the State, the rocks of which consist of strongly folded and faulted quartzites, limestones, slates, schists, etc., mostly of Paleozoic age, which by their erosion have given rise to the rugged topography characterizing the region. To the east the Berkshire Hills grade off into a less rugged and somewhat lower region of similar rocks and structure, which extends to the borders of the Connecticut Valley lowlands. These lowlands are marked in general by the presence of soft reddish Triassic sandstones and shales, with an occasional trap bed forming the ridges. They extend from the Connecticut line, where they have a width of 20 miles or more, northward to their termination, a few miles south of the New Hampshire line. East of the Connecticut Valley a belt of folded sedimentary or metamorphic rocks is first encountered, beyond which the broad crystalline belt, consisting largely of igneous rocks, but including many altered sedimentary beds, extends eastward to the coast. In the vicinity of Boston, and extending southwestward for some distance, and again in the vicinity of Narragansett Bay, and in the region to the northeast, there are considerable areas of Carboniferous sandstones, conglomerates, and slates. Cape Cod and a portion of the adjacent region consist superficially entirely of gravel, sands, etc., of glacial derivation.

Over the whole of the surface of the State is spread a mantle of drift left by the glaciers which once covered the region. This is of two types, a distinction being made between till, bowlder clay, or hardpan, as it is variously known, and the different forms of stratified drift, including, besides more or less distinctly stratified gravel and sand, large amounts of bedded clay or rock flour. The till is a nearly universal deposit. It attains its greatest average thickness on the upland surfaces, and its maximum thickness in the rounded hills known as drumlins and in moraines left by the ice sheet which once covered the region. In the valleys and over the lowland generally the till is to a large extent covered and concealed by the stratified drift. Except in moraines, the till is prevailingly well compacted, a true hardpan, and contains enough clay and rock flour to make it essentially impervious. Hence, save where it contains layers of gravel or sand, it must be reckoned as an unreliable water horizon as far as large volumes are concerned, but it is nevertheless the source of supply of thousands of small wells used for domestic and farm purposes. Its chief function, however, is to impound and to control or direct the movement of the water of overlying sands and gravels.

Of the stratified drift, the coarser phases, including the gravel and sand and much of the rock flour, are confined chiefly to the valleys and to the lower portions of the surface, occurring largely as overwash and delta plains, formed by glacial streams.

WATER SUPPLIES.

AREAS CONSIDERED.

The drift is by far the most important and reliable source of underground waters, and this fact makes the tracing and detailed mapping of these deposits a matter of special interest. The principal areas only may be mentioned here. These are the Berkshire Valley; the valleys of the Connecticut and its principal tributaries, where the flood plains and terraces have their chief development; the Nashua Valley, with the delta plains, etc., of glacial Lake Nashua; the Merrimac Valley, with widespread delta and overwash plains; the Boston basin, with the delta plains formed at many different levels in the series of glacial lakes once existing there; the overwash and other plains of the Blackstone Valley and the basin of Narragansett Bay; the widely-extended plains of varied origin in southeastern Massachusetts and on Cape Cod north of the inner moraine; the overwash or apron plains of the inner moraine on Cape Cod, east of Woods Hole; and the similar plains of the outer moraine, on the south sides of Marthas Vineyard and Nantucket.

The Pleistocene or glacial clays are normally composed in large part of rock flour; but in spite of this fact they must be regarded as practically impervious and of no interest as available sources of underground water, ranking even below the till in this respect. It is fortunate, therefore, that the glacial clays have deen deposited at relatively low levels and in the coastal areas, mainly below sea level. Water is occasionally obtained from sand or gravel underlying the clays, in which case it may have considerable head.

BERKSHIRE VALLEY.

This is an area of complexly folded and faulted sedimentary formations, mostly of early Paleozoic age, including in succession a basal Cambrian quartzite outcropping along the east side of the valley, the great crystalline Cambro-Ordovician limestone forming the floor of the valley at most points, and the metamorphic slates and schists of the Greylock and Taconic ranges. Although the quartzite is in part of a distinctly friable and permeable character, as is so well shown where it is quarried as a glass sand, and is, therefore, entitled locally to some consideration as a water horizon; the topographic relations of the limestone to the valley, regardless of other considerations, determine it as the chief bed-rock source of water. Its crystalline texture makes the limestone practically impervious and limits its water-bearing capacity to joints and fault fissures, which, however, may be appreciably widened by solution. The structure is not very favorable to artesian flows, except perhaps very locally. Though somewhat uncertain in its occurrence water is usually found in the deeper wells. It is possible that borings through the limestone at certain points might develop artesian sources in the underlying quartzite. The rock waters of the Berkshire Valley are, in general, distinguished by their hard or calcareous character, and considerations of quantity and quality combine to make them relatively unimportant.

The drift of the Berkshire region is chiefly till, and the stratified drift is mainly confined to the bottoms of the valleys, being most abundant, as a rule, where the valleys are broadest, as in the latitude of Williamstown and North Adams, at elevations below 860 feet; of Pittsfield and Richmond, mainly below 1,000 feet; and of Lenox and Lee, where existed glacial Lake Housatonic at an elevation of about 1,000 feet. South of Great Barrington the stratified drift, with a normal elevation of 700 feet, and a breadth varying from 1 to 2 miles, is continuous to the State line and beyond. The topographic relations of these deposits insures to them not only the precipitation belonging to their areas, but also a large part of the rainfall on the bordering slopes of till, and since their own contours determine a shallow water table, it follows that they must be regarded as very important and readily available reservoirs of the ground water. As in other limestone regions, the drift is more or less calcareous, as is evidenced at times by its local cementation, but rarely to such a degree as to make the water sensibly hard.

CONNECTICUT VALLEY.

The great thickness in this valley of arenaceous strata, characterized throughout by moderate monoclinal dips, is very suggestive of artesian conditions. It does not appear, however, that this can fairly be described as an artesian basin, although in many wells the water rises nearly to the surface and occasionally flows. The best wells are in the sandstone areas. In the conglomerate or arkose areas even the deep wells sometimes fail to obtain water. The waters are always hard, especially in the shales, and it is frequently impossible to use them in boilers.

The drift of this great valley, as previously noted, is chiefly stratified, the unmodified drift or till being almost entirely restricted to the lenticular hills or drumlins, of which there are several notable groups; and the modified or stratified drift, occurring in the forms of lake beds, deltas, terraces, and flood plains, attains in places, and especially in the axis of the valley, a considerable thickness. In fact it is one of the principal storage reservoirs of New England, a large majority of the successful wells, as well, probably, as most of the springs, deriving their water from it. Over a large part of the valley, and especially on the low-lying plains as distinguished from the terraces, the water table is near the surface, and shallow wells afford an unfailing supply. The drift waters are nearly always soft.

EASTERN AND WESTERN HIGHLANDS.

The western highlands include the elevated hilly region between the Berkshire Hills and the Connecticut Valley belt, while the eastern highlands embrace the similar but less hilly region to the east of that valley.

The two regions are alike in having igneous and metamorphic bed rock, thinly covered with till on the uplands. The modified drift is confined chiefly to the valleys and is naturally most abundant in the broader valleys of the eastern highlands. This is, as usual, the chief and most available source of the ground water; and it is partly for this reason that we find the population massed upon it, the till of the uplands, as a rule, supporting only a sparse farming population. During the recession of the ice sheet the conditions favored the development of temporary glacial lakes in the valleys, especially of the eastern highlands, and at all elevations up to 1,000 feet or more; and thus may be explained bodies of modified drift of exceptional volume and depth, lying sometimes at such elevations as to make them important storage reservoirs for ground water.

Although everywhere relatively superficial, the ground water is naturally pure and soft, and a study of the topographic map shows relatively little obstructed drainage with consequent swampy conditions and peaty waters. On the other hand, the frequently dense village populations on the narrow and shallow valley deposits of sand and gravel present conditions especially favorable to contamination of the ground water and suggest the introduction of a public supply from similar deposits farther up the valley, or from the surface streams or ponds of the uplands. The till of the uplands, derived from metamorphic and highly quartzose formations, is doubtless of an exceptionally arenaceous and porous texture, and this feature, supplemented by occasional interbedded and superficial layers of washed material, will readily account for the water supply, often copious and excellent, of the farms.

NASHUA VALLEY.

This valley is excavated along a belt of altered slaty rocks in northeast Massachusetts. It is a relatively limited and simple tract, lying in the valley of the northward draining Nashua River, and hence presenting exceptionally favorable conditions for the development of glacial-lake phenomena, including broad and deep deltas or sand plains. These occur at various levels, but are rather limited in extent above 440 feet, and have their chief development below 370 feet. Above the lake levels stratified gravels and sands occur but scantily, and the till or hardpan, derived largely from slaty rocks, is of a relatively argillaceous and impervious character.

Bed-rock wells, whether sunk in the slaty rocks or in the bordering schist and granite, must in general be of little value, and, as on the highlands, artesian conditions do not exist except perhaps very locally, where the rocks are traversed by favorable fissures.

COASTAL LOWLANDS.

In density of population and consequent demand for water this area leads all the rest. But the concentration of the population in cities necessitates the extensive utilization of surface waters, while the ground waters have been found available chiefly for the smaller communities and private interests. This is a region of crystalline, igneous, and metamorphic rocks, with the exception of the sedimentary deposits, chiefly conglomerates and slates of Carboniferous age, of the Boston, Norfolk, and Narragansett basins. Deep rock wells are more common in this region, especially in the vicinity of Boston, than in any other part of New England. On the crystalline formations the proportion of decidedly successful wells is not large, and the result of a boring can not be predicted. In the Carboniferous slates, as proved by numerous examples in Boston, Cambridge, etc., there are very few successful wells, the water being almost invariably inferior in both quality and quantity. In the conglomerate series are many good wells and comparatively few failures. In no case, probably, are the rock waters yielded chiefly by interstitial flow; the good wells are those that intersect favorable systems of joints and other fissures, and in this connection it may be noted that the joint structure of the conglomerate is exceptionally distinct and open.

This is a region of abundant drift deposits. The stratified drift, including sand and gravel which is largely referable to glacial lakes or local apron plains, is widespread and, as usual, is the principal source of the ground water, supplying even some of the larger cities, such as Lowell and Providence. These deposits, as previously noted, become more continuous southward in the region of Narragansett Bay and Cape Cod Bay, and attain, no doubt, a considerable thickness. They may be regarded as a vast and practically inexhaustible reservoir of water, which, with a uniformly shallow water table, is readily available by pumping and far exceeds in quantity the demands of the present population. These statements may be repeated for the great apron plains south of the terminal moraine, on the south side of Cape Cod, and on Marthas Vineyard and Nantucket.

NORMAL CHLORINE.

The normal chlorine, or maximum proportion of chlorine (present as common salt or sodium chloride) which may exist in an uncontaminated water, usually varies inversely as the distance from the sea, the range for Massachusetts being from 2.42 parts per 100,000 at Provincetown and 2.16 parts on Nantucket to 0.06 parts in Berkshire County. The normal chlorine not only depends upon the proximity to the coast, but it is highest on the salient and most exposed parts of the coast, where the surf breaks heavily and the salt spray is wafted inland most freely. Higher amounts than those indicated are due either to peculiarities of the rocks or drift from which the water comes or to pollution by sewage. In New England it is commonly the latter which gives rise to high chlorine, and waters containing this constituent in amounts distinctly above the normal should be avoided for domestic purposes.

MINERAL SPRINGS.

MASSACHUSETTS.

Massachusetts has the distinction of possessing a larger number of springs from which waters are shipped than any other State in the country. In 1902 there were 75 such springs that reported shipments, the next largest number being 56, in New York. One reason for the large number of springs reporting sales lies in the fact that many of them are located near cities in which the demand for spring waters for table purposes is very large. The total sales in the year mentioned amounted to 8,475,365 gallons, having a value of $562,973. Following is a list of the springs reporting:[a]

Abbotts Spring, Methuen, Essex County.
Arctic Polar Spring, Spencer, Worcester County.
Ballardvale Lithia Spring, Andover, Essex County.
Beach Hill Spring, Stoneham, Middlesex County.
Beaver Dam Spring, Scituate, Plymouth County.
Belmont Crystal Spring, Belmont, Middlesex County.
Belmont Hill Spring, Everett, Middlesex County.
Belmont Natural Spring, Belmont, Middlesex County.
Berkshire Crystal Spring, Sheffield, Berkshire County.
Berkshire Sodium Spring, Sheffield, Berkshire County.
Bodwell Spring, Lawrence, Essex County.
Burnham Spring, Methuen, Essex County.
Chapman's Crystal Mineral Spring, Stoneham, Middlesex County.
Crystal Mineral Spring, Methune, Essex County.
Crystal Spring, Brockton, Plymouth County.
Deep Rock Spring, Lynnfield Center, Suffolk County.
Diamond Spring, Lawrence, Essex County.
El-azhar (formerly Sheep Rock) Spring, Lowell, Middlesex County.
Electric Spring, Lynn, Essex County.
Everett Crystal Spring, Everett, Middlesex County.
Farrington's Silver Spring, Milton, Norfolk County.
Fulton Natural Spring, Medford, Middlesex County.
Garfield Spring, Weymouth, Norfolk County.
Geddes Mineral Spring, Marlboro, Middlesex County.
Goulding Spring, Whitman, Plymouth County.
Highland Spring, North Abington, Plymouth County.
Howe Spring, Millbury, Worcester County.
Howland Spring, Dartmouth, Bristol County.
Hygeia Artesian Well, Springfield, Hampden County.
Ingersoll Grove Spring, Springfield, Hampden County.
Katahdin Spring, Lexington, Middlesex County.
King Philip Spring, Mattapoisett, Plymouth County.
Läkoo Indian Crystal Spring, Lawrence, Essex County.
Lang Moore Spring, Natick, Middlesex County.
Larchmont Spring, Lexington, Middlesex County.
Leland Spring, Natic, Middlesex County.
Lexington Spring, Lexington, Middlesex County.
Linden Mineral Spring, Linden, Middlesex County
Lovers' Leap Springs, Lynn, Essex County.
Magnolia Spring, Gloucester, Essex County.
Massasoit Spring, West Springfield, Hampden County.
Middlesex Mountain Spring, Medford, Middlesex County.
Milton Spring, Milton, Norfolk County.
Monatiquot Spring, South Braintree, Norfolk County.
Moose Hill Spring, Swampscott, Essex County.
Mount Blue Spring, Hingham Center, Plymouth County.
Mount Holyoke Lithia Spring, South Hadley, Hampshire County.
Mount Orient Spring, Pelham, Hampshire County.
Mount Pleasant Spring, Lowell, Middlesex County.

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[a] Peale, A. C., Mineral waters U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

Mount Washington Cold Spring, Chelsea, Suffolk County.
Myles Standish Spring, South Duxbury, Plymouth County.
Nashoba Minerel Spring, Westford, Middlesex County.
Nemasket Springs, Middleboro, Plymouth County.
Nobscot Mountain Spring, Framingham, Middlesex County.
Norwood Spring, Norwood, Norfolk County.
Pearl Hill Mineral Spring, Fitchburg, Worcester County.
Pepperell Mineral Spring, Pepperell, Middlesex County.
Pequot Spring, North Natic, Middlesex County.
Purity Spring, Spencer, Worcester County.
Ravenwood Spring, Gloucester, Essex County.
Robbin's Spring, Arlington Heights, Middlesex County.
Sager Spring, Danvers, Essex County.
Sand Spring, Williamstown, Berkshire Couuty.
Shawmut Spring, West Quincy, Norfolk County.
Silver Seal Spring, Woburn, Middlesex County.
Simpson Spring, South Easton, Bristol County.
Smiley Spring, Haverhill, Essex County.
Steavens's Spring, Lawrence, Essex County.
Sunnyside Spring, Franklin, Norfolk County.
Swampscott Spring, Swampscott, Essex County.
Trapelo Spring, Belmont, Middlesex County.
Undine Crystal Spring, Brighton, Suffolk County.
Valpey Spring, Woodland, Lawrence, Essex County.
Whitman Spring, Whitman, Plymouth County.
Wilbraham Mountain Spring, Wilbraham, Hampden County.

RHODE ISLAND.

The number of springs reporting sales in 1902 in this State is four. They are as follows:

Berry Spring, Pawtucket, Providence County.
Gladstone Spring, Narragansett Pier, Washington County.
Holly Mineral Spring, Woonsocket, Providence County.
Ochee Mineral and Medicinal Springs, Johnston, Providence County.

The total sales reported amount to 244,212 gallons, having a value of $26,588.[a]

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey, No. 32, pp. 21-24.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, 1902, p. 51.

Massachusetts and Rhode Island [well and spring records], by W. O. Crosby, Laurence La Forge, and F. A. Champlin: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, 1904, pp. 94-125.

Drilled wells of the Triassic area of the Connecticut Valley, by W. H. C. Pynchon: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1905, pp. 65-94.

Triassic rocks of the Connecticut Valley as a source of water supply, by M. L. Fuller: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, pp. 95-112.

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[a] Peale, A. C., Mineral waters U. S. for 1902, U. S. Geol. Survey. 1904, p. 996.

CONNECTICUT.

By H. E. Gregory.

A study of the water resources of Connecticut, based on a large number of records of wells and springs, shows that next to rainfall the nature of the rocks or deposits is the factor of greatest importance. In fact the character and availability of the water supply are directly dependent upon two geologic factors—the composition of the rock or other material, and the number of fault or joint fissures it may possess.

RAINFALL.

The annual rainfall in Connecticut is 46.89 inches. This is distributed throughout the year as follows: January, 4.28; February, 3.94; March, 4.23; April, 3.53; May, 4.03; June, 2.95; July, 4.42; August, 4.30; September, 3.34; October, 4.04; November, 4.48; December, 3.44. This is sufficient, when taken in connection with small evaporation, to form a constant supply for the streams of the State, which carry off about 40 per cent of the water that falls, and to furnish abundant ground water. So that, so far as Connecticut is concerned, the available water supply depends on the capacity of the rock and the surface cover of land waste to hold the water.

GEOLOGY AND WATER SUPPLY.

Geologic subdivisions.—As to the characteristics of rock structure which affect underground water, Connecticut is divided into three parts: The limestone (Stockbridge dolomite) area of the upper Housatonic Valley, the Triassic sandstone area of the Connecticut Valley lowland, and the crystalline area of metamorphic rocks occupying the remainder of the State. A small area in the valley of Pomperaug River has the same characteristics as the Connecticut Valley lowland. The map, fig. 17, shows the distribution of the different classes of rock.

Limestone area.—The parts of the State underlain by the limestone are not densely populated. They contain no large cities, and the chief pursuits are dairying and mixed farming. The limestone rock varies greatly in its water-bearing capacity, and wells have usually to be sunk to a considerable depth before a supply is assured. Of nine wells selected as typical, four are over 150 feet in depth (155, 171, 182, 210 feet, respectively), and only one is less than 50 feet. When wells are sunk this deep the supply is plentiful and does not vary with the seasons. The water is hard, containing calcium, magnesium, and iron. The springs issuing from rock in the limestone area show abundant, constant flow and low temperature. In one case an invariable temperature of 45 degrees is reported.

Triassic sandstone area.—The bed rock of the Connecticut Valley lowland is sandstone with interbedded basalts and intruded diabases. The sandstone varies in texture from coarse conglomerate to fine clay shales and is sufficiently porous to hold 20 to 30 per cent of its volume of water. For this area it seems to be true that the deeper the well the more abundant the water supply down to about 500 feet, and that there are no distinct water-bearing beds. Wells are all deep, averaging for the whole area over 100 feet. One well at New Haven was sunk to a depth of 4,000 feet by the Winchester Arms Company in an unsuccessful effort to obtain a flowing well. The conditions for artesian water are better in the Triassic rocks than elsewhere in Connecticut, but are very unfavorable. While it is true that the sandstones contain abundant water, yet their composition, texture, and position are extremely irregular. They are not arranged in definite series, and they have been shattered by the forces which produced the faults in the valley. There is, therefore, no continuity of stratification and no arrangement of water-bearing beds favorable for artesian wells. The practice among well drillers in Triassic rock is to sink the well

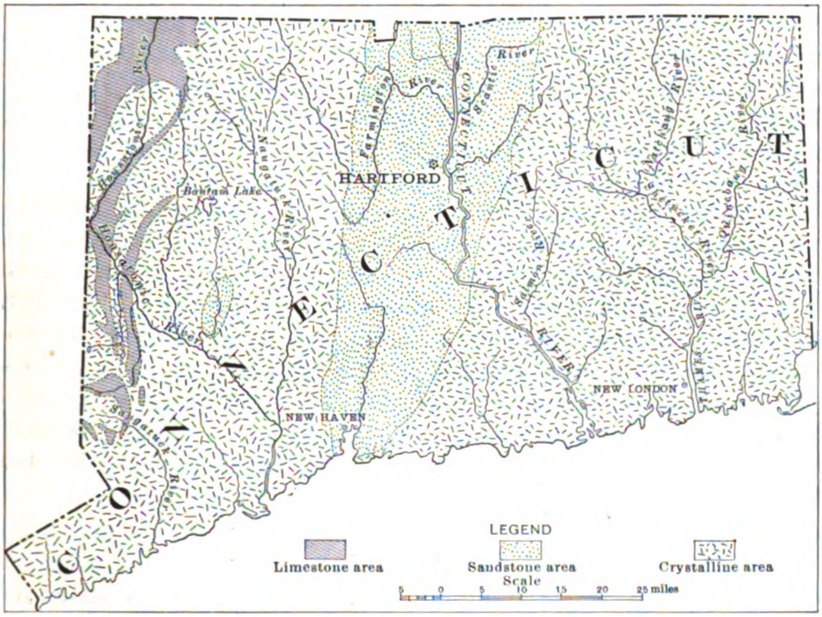

FIG. 17.—Areas of limestone, sandstone, and crystalline rock water supplies of Connecticut.

20 to 50 feet below the first supply of water, so as to have a reservoir below. Most of the deep-drilled wells afford a constant supply, but two wells show a decrease and five an increase since they were made. The cost of 60 selected wells averages $280.80, and the cost of pumping apparatus $240.20. More than half of the wells in sandstone supply hard water. Springs in the sandstone area that are known to issue from rock come up along deep-seated cracks and are much colder than the springs formed in glacial materials.

The Triassic area, although it constitutes one-fifth of the State, contains one-third of the population and the most productive farms (averaging $20 per acre in annual value of crops), as well as the largest cities. It is the tobacco center, the manufacturing center, and the railroad center of the State, and is steadily increasing in population. The water supply is the best in the State, but because of the growing population it is becoming an important economic problem. At present the large cities are supplied by lakes and other surface waters, in some cases brought from considerable distances. These supplies are not inexhaustible and studies of other sources are being made. The very marked difference in character and density of population in the Connecticut Valley lowland and the crystalline highland is due partly to the conditions which control the water supply.

Crystalline area.—As shown on the map the area underlain by metamorphic crystalline rocks constitutes a large portion of the State. These rocks are remarkably variable in texture, are folded, twisted, broken, and cut by ancient intrusions and veins, and do not furnish favorable water-bearing conditions. Moreover the run-off constitutes a larger part of the rainfall than in the sandstone or limestone areas. The wells for which records are collected in the crystalline rocks (gneiss, mica-schist, etc.) average 125.8 feet in depth, and the principal water horizon lies 107 feet below the surface. Some of the deepest wells show no water below the first water horizon. Of 34 typical wells, 25 contain hard water, 2 show sulphur traces, 4 iron. The average cost of drilling these wells is $678 and of the pumping apparatus, $162. Some wells have been sunk in the crystalline area which have resulted in complete failure after the expenditure of thousands of dollars. The conditions governing the flow of underground water in metamorphic rocks are not well understood, and it is hoped that arrangements can be made to investigate the water resources of this area, especially along the coast line, where the summer population is increasing yearly.

Springs in the crystalline area known to issue from rock are fairly abundant and yield an unfailing supply. Nearly all of those which have been examined are located along lines of faulting and, judging from their constant low temperature, come from considerable depth.

With the exception of the valleys possessing water power, the crystalline area is given over to mixed farming, and the population is scattered and in many places is decreasing. The State of Connecticut has added 162,000 to its population in the last ten years, yet during that time 55 townships located on the crystallines have decreased in population. One whole county (Tolland) showed a net decrease of about 1,400 between the years 1890 and 1900. The value of farm products on the crystalline uplands has increased somewhat during the past decade, yet it barely exceeds $10 per acre, and the proportion of improved land to total area is less than 10 per cent.

Faults.—Connecticut is traversed by sets of fault planes running in three or four principal directions. The breaks have produced profound effects on the topography and exert a marked influence on the water resources. They control in part the direction of Connecticut rivers and are the chief cause for the many deep, cold springs of the State, and especially of the mineral springs used for table waters. The springs near South Britain, those which supply water to the village of Collinsville, and the Stafford springs are examples of those which are believed to owe their origin to deep-seated fault cracks. Springs from such deep sources form valuable water supplies and a study is being made of their distribution and character and of means for their fuller utilization.

Water supply of the drift.—The entire State of Connecticut has been overridden by the ice of the Glacial epoch, and this fact has greatly affected the water supply. The numerous lakes, ponds, swamps, and many of the smaller streams owe their position and their very existence to the continental ice sheet. Of particular value to man are the hundreds of lakes, which constitute the principal water supply for cities and villages. The soil of Connecticut also dates from the Glacial epoch, and its character as a water bearer is determined by this circumstance. The bed rock is covered nearly everywhere by one of two kinds of glacial material: (1) Till, which was deposited directly by the ice, and which is a heterogeneous, unassorted mass of bowlders of different sizes embedded in clays of variable texture and composition; (2) stratified drift, which is made up of sands, gravels, and clays, sorted as to size and deposited in layers, and which owes its structure to the fact that it was deposited by water.

The till occupies all the highlands of the State, forming a mantle, usually but a few feet in thickness, over the crystallines and over the trap ridges of the Triassic area. Wells in till are usually shallow, rarely over 50 feet in depth, and it is the practice to sink them but a few feet below the principal water horizon. Seventeen wells are reported as being less than 10 feet in depth and yet containing an abundant supply of water. In general, the wells of the till area contain soft water, which varies in amount with the seasons. During an unusually dry summer the wells in some sections dry out entirely. The till-covered crystallines are being occupied by hotels, sanitariums, and country estates, and the problem of the increased water supply for these is becoming more and more important.

The springs of the till area furnish prevailingly soft water, and, like the wells, show their connection with the rainfall by their variation from year to year and from season to season. Except in extraordinary years the variation is slight, because the Connecticut rainfall is evenly distributed throughout the year. (Rainfall at New Haven: Spring, 11.67 inches; summer, 12.79; autumn, 11.67; winter, 11.84.)

Stratified drift forms the cover over a large part of the sandstone district, and also occupies the valleys in the crystallines. It varies in depth from only a few inches to over 500 feet, and because of its prevailingly loose texture forms a water reservoir of great capacity. On the New Haven sand plain and in general throughout the Connecticut Valley lowland, water maintains a permanent level 20 to 30 feet below the surface, and the practice is to sink the wells to some distance below this water horizon, so that a reserve supply is always on hand. Where large quantities of water are required for boilers, manufactories, swimming pools, etc., several wells are sunk in close proximity and connected with one pump. Yale University uses 34 such wells to supply water for the gymnasium. The wells in the stratified drift, for the most part, furnish pure water and indicate an available supply which may be used as the cities increase in size. Wells are nearly all driven, and cost on an average $348. The pumping apparatus costs on the average $250. Springs in stratified drift are not numerous, and they vary in size according to the relative thickness and position of the sand and clay layers. Many are wet-weather "seeps;" others furnish sufficient supply for a farmhouse; a few, like the Pequabuck Spring, near Bristol, have sufficient water to form a brook.

Mineral springs.—Fourteen springs in the State furnish water for table use and for medicinal purposes. The Arethusa Spring, at Seymour, which is perhaps best known, marketed 38,000 gallons of water in 1902. Extreme purity is the chief characteristic of the springs located along fault lines, although in a few cases the analyses show the presence of lithium, magnesium sulphate, and other ingredients which give them medicinal values. The pure and abundant spring water is an extremely valuable commercial asset for the State.

The springs reporting sales in 1902 are given in the following list. The total output is reported as 307,000 gallons and the value as $194,085.[a]

Althea Springs, near Waterbury, New Haven County.
Arethusa Spring, Seymour, New Haven County.
Aspinock Mineral Springs, Putnam Heights, Windham County.
Cherry Hill Spring, Hamden, New Haven County.
Granite Rock Spring, Higganum, Middlesex County.
Live Oak Spring, Meriden, New Haven County.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

Mohican Spring, near Bridgeport, Fairfield County.
Oxford Mineral Spring, Oxford, New Haven County.
Park Spring, Willimantic, Windham County.
Puritan Spring, Norwich, New London County.
Stafford Mineral Spring, Stafford Springs, Tolland County.

Each year more land of the till-covered uplands, which has proved unprofitable for farming, is being purchased for country residences and large estates. For these purposes an abundant supply of water of unquestionable purity is indispensable.

It is of scientific interest that the Indian Rock spring water at New Milford and also the surface water at New Haven have been shown to be radio-active.

With the exception of the medicinal waters the Connecticut supply is used almost entirely for domestic and manufacturing purposes, and for these uses is uniformly good. Very rarely are wells or springs or surface supplies unfit for domestic use and only a few manufacturers report water unsuited for boilers or for washing fabrics.

Stream supplies.—The larger rivers of the State are not at present directly available as water supply because the sewage and refuse from manufacturing establishments are emptied directly into them. They thus stand as a large unimproved resource which may be developed whenever the demand for increased domestic water supply justifies the expense of installing plants for the purification of sewage.

Irrigation.—Irrigation is practiced to a small extent in Connecticut, and wherever used the results more than justify the expense. There are but few crops which have all the water necessary for their maximum yield. Hay, in particular, needs abundant water, and is one of the most valuable crops of Connecticut. There is no doubt but that the yield of most field crops could be greatly increased both in acreage and amount per acre by the use of water. The valleys of the crystalline uplands which are now sparsely settled are particularly adapted to irrigation, and it seems evident that a more intelligent use of the soil, the woodlands, and the water resources of the State could win the unimproved and abandoned lands to profitable agriculture.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 25, 26.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, 1902, p. 20.

Connecticut [well and spring records], by H. E. Gregory, F. A. Champlin, and C. L. Grant: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, 1904, pp. 127–168.

Drilled wells of the Triassic area of the Connecticut Valley, by W. H. C. Pynchon: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1905, pp. 65–94.

Triassic rocks of the Connecticut Valley as a source of water-supply, by M. L. Fuller: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1905, pp. 95–112.

NEW YORK.

By F. B. Weeks.

In the State of New York, as in other regions where there is no considerable variation in the amount of rainfall or in the rate of evaporation, the occurrence and character of the underground waters are very largely determined by the topography, by the character of the soil and underlying rocks, and by the structural features of the strata.

PHYSIOGRAPHY.

The State may be divided into five distinct physiographic provinces, viz, (1) Adirondack, (2) Eastern (Taconic), (3) Catskill, (4) Allegheny Plateaus, (5) Ontario. The Adirondack province is the only one lying wholly within the State, the others forming parts of larger topographic divisions which extend beyond its limits.

1. The Adirondack province, second in size, comprises a mountainous area flanked on all sides by a lower, hilly country. It is drained by headwaters of streams flowing into St. Lawrence, Hudson, Black, and Mohawk rivers.

2. The eastern (Taconic) province in its northern part is hilly or mountainous, being formed by the Taconic ranges, which extend into Vermont and Massachusetts, while in its southern part it becomes more gently undulating. It is principally drained by short streams flowing into the Hudson.

3. The Catskill province is composed in part of folded rocks of the northern extension of the eastern Appalachian ridges, and in part of horizontal rocks, and on the west merges into the Allegheny Plateaus province. This region has been deeply dissected by streams which flow into Hudson, Delaware, and Susquehanna rivers.

4. The Allegheny Plateaus province occupies one-third of the State, comprising the area south of the Ontario province from Lake Erie to the Catskills. It contains a number of broad river valleys and is drained by streams that flow into Susquehanna, Allegheny, and Genesee rivers.

5. The Ontario province extends in a rather narrow band around Lake Ontario from the Niagara to the St. Lawrence and is drained by

short streams, some of which form the outlets of the so-called Finger lakes.

The accompanying map (Pl. V) shows the main drainage lines in the State and from these the outlines of the several physiographic provinces may be deduced. The distribution and lithologic character of the several geologic systems represented in the State have been indicated, except the Quaternary. Those springs which are of commercial value are also noted on the map. They include all springs thus far reported whose waters are sold or used in connection with manufacturing enterprises or public water supply.

GEOLOGY AND UNDERGROUND WATERS.

The underground waters will be discussed under the several geologic divisions.

Pre-Cambrian.—The pre-Cambrian system is composed of ancient crystalline rocks and of more or less metamorphosed stratified rocks which can not readily be separated from them. Pre-Cambrian rocks form the greater part of the Adirondack region and also outcrop in the southeastern part of the State. No distinct water-bearing beds occur in these rocks, since the most of them are not stratified or have been so greatly compressed and folded that the stratification planes are no longer even approximately horizontal. The ground water descends along fracture planes and can be obtained at various depths.

In the Adirondacks there are a great number of springs, such as are common in mountainous areas. They are the sources of the many streams that drain the region. The inhabitants depend very largely upon streams and springs for domestic and stock-water supply. The few wells reported obtain their water from sands and clays overlying the hard rocks. In the southeastern part of the State the pre-Cambrian system consists of granites, gneisses, and metamorphic rocks, compressed into folds which have a northeast-southwest direction, and which outcrop in New York, Orange, Putnam, and Westchester counties. In Putnam and Westchester counties several springs having a flow of 100 to 300 gallons an hour, and many smaller springs are reported. The water from a few of them is bottled and sold. Records of deep wells up to 250 feet have been obtained. The deep wells are pumped by windmills or other power and furnish from 30 to 250 barrels a day. The waters of these wells are usually soft. By far the greater number of wells are dug or blasted in rock. These are from 6 to 50 feet deep, and three-fourths of them are said to fail during protracted droughts. The water is frequently reported as alkaline.

Cambrian.—The Cambrian limestones and slates extend in a long, narrow band through Washington and Rensselaer counties into Columbia. These strata have been greatly affected by folding and faulting, which, together with the considerable variation in the lithologic character of the rocks, frequently cause a marked difference in depth to water horizons and in the character of the water within short distances. There are springs of large flow in this region, and the supply of many of them, which appears to come from Quaternary sands and clays, is probably largely derived from the underlying strata. At Cambridge and Shushan, in Washington County, springs of very large flow are reported. At other localities springs are utilized to fill ice ponds and also furnish water power for small feed and sawmills. Most of the wells in the area are less than 100 feet deep. Their waters, except those in the limestone lenses, are soft. In the town of Cambridge, Washington County, a well drilled to a depth of 39 feet furnishes 150 to 200 gallons an hour and may be considered an average well of the region.

The Cambrian sandstone (commonly known as the Potsdam sandstone) occurs on the northern side of the Adirondacks and also in detached areas, too small to be shown on the map, on the southeastern and southern flanks. It is usually a compact sandstone varying in color from light gray to buff and sometimes reddish-brown. No records of deep wells in these sandstones have been obtained. Dug wells 20 to 50 feet deep furnish a sufficient supply for domestic purposes. Small springs are very abundant, but none of very much economic importance are known.

Ordovician.—The strata which are called Ordovician consist of a great thickness of limestone and shales, often intensely folded and highly metamorphosed. They form the surface rocks of the Mohawk River Valley, extending in a northwesterly direction from Albany to Lake Ontario along the southeastern, southern, and southwestern sides of the Adirondack area. They also occupy the greater part of the region east of Hudson River south of Lake Champlain, and south of Kingston they extend in a southwesterly direction beyond the New Jersey line. They also occur in a narrow strip along the St. Lawrence. Within these areas many springs of considerable economic importance, including a large number of mineral springs, come to the surface. They are particularly abundant in the valley of the Mohawk, and in a number of localities furnish water power and in others supply creameries, railroad tanks, etc. The celebrated mineral waters of Saratoga Springs and vicinity are found in fractured zones of the Trenton limestone, where they occur in a narrow belt extending for several miles in a northeast-southwest direction. The shale strata form the greater part of this system and afford the larger part of the water supply.

Massena Springs, in St. Lawrence County, and Lebanon Springs, in Columbia County, are old, well-known mineral spring resorts, the latter being the only thermal water in the State.

In some areas, as in southwestern Montgomery, in Albany, Colum-

bia, and other counties, wells yield from 50 to 200 gallons per minute, the water being obtained in the shales at depths of 100 to 500 feet. In some of the wells the water is hard, in others it is soft, and in many it contains considerable gas. These artesian areas are determined by varying local conditions of structure and rock composition. Wells that require pumping are very abundant, and the depth to water in the solid rocks varies with the thickness of the glacial sands and gravels which cover a large part of the Ordovician strata. The water of such wells is usually abundant, but it is frequently impregnated with iron, sulphur, and gas, which in some instances renders it unfit for drinking.

Silurian.—The Silurian rocks outcrop in a narrow band from the New Jersey line northeastward to Kingston and northward to a point opposite Albany, where the belt bends to the northwest and occupies much of the Ontario province. The sandstones that form the lower part of the system extend along the southern shore of Lake Ontario and on its eastern shore spread out over a broad area north of Oneida Lake. As the greater part of this area is covered with glacial deposits, the springs may derive their waters wholly from these beds. Several important mineral springs are found in this region, notably those of Oswego, from which water has been sold since 1870. The wells that penetrate the sandstones range in depth from 50 to 125 feet, and furnish large supplies of water, which is usually hard.

South of these sandstones is an area of limestone, in which springs of hard water are fairly abundant. No important mineral springs occur in it. In Orleans, Monroe, and Wayne counties wells drilled to depths ranging from 75 to 125 feet obtain supplies amounting in some cases to 150 gallons per hour. This limestone area narrows eastward and disappears south of Utica.

The highest rocks of this system are generally shales, and extend from Niagara River eastward in a belt parallel to the limestones and sandstones. Nearly all the waters from these shales contain mineral matter in varying amounts, and many of them are used for medicinal purposes. The water of Oak Orchard Springs, in Genesee County, is remarkable for its content of free sulphuric acid, which is a rare constituent of mineral water. In Oneida County there are a large number of mineral springs and wells near Clinton, Franklin Springs, Kirkland, and Booneville, from which water is bottled and sold. These waters come from near the junction of the sandstones and shales. One of the deep wells in this county is at Deansboro. This is 300 feet in depth and the water rises within 20 feet of the surface and is used for cooling milk. In Niagara County near Lockport a well 115 feet deep penetrated the shales and the water flows during the winter months. Near Henrietta, Monroe County, is a flowing well 65 feet in depth, which is said to afford a large supply of water.

The southern limit of the Silurian is marked by a narrow band of sandstone extending from Genesee County eastward, and along or near the line of contact there are many springs. Among these are mineral springs near Williamsville, Honeoye Falls, Clifton Springs, Chittenango Springs, and Sharon Springs.

Devonian.—Rocks of this system cover practically all the Allegheny Plateaus and Catskill provinces. It contains two prominent narrow limestone bands and a great thickness of shales and sandstones. The entire thickness of the series has been estimated at about 3,400 feet. The Silurian sandstone, just described, is succeeded to the south by a prominent limestone, which is followed farther south by a series of shales. Along the contact of this limestone and shale several important mineral springs occur. Prominent resorts and sanitariums are located at Avon, Richfield Springs, and Cherry Valley. Still farther south are springs at or near Penn Yan, Dryden, Watkins, Slaterville, and Spencer, their waters being derived from the upper portion of the Devonian sandstones and shales.

In the central and northern portions of the Devonian area comparatively few flowing wells have been reported. In Chautauqua, Cattaraugus, and Allegany counties most of the wells in rock, 100 to 500 feet deep, flow and furnish up to 1,000 gallons an hour. They are principally used for domestic purposes, creameries, oil-pumping machinery, and various manufacturing establishments. Some of them are mineralized and are considered beneficial in treating various diseases. In the southern tier of counties east of Allegany County the number of flowing wells decreases, but large supplies of water are obtained by pumping. An appreciable amount of iron and sulphur is found in the waters of many of the wells throughout the Devonian area.

Triassic.—The rocks of this system are reddish sandstone and diabase and outcrop in Rockland County. Water comes to the surface along the line of contact of these rocks in springs and seeps. At West Nyack and Bardonia the flows are estimated at 100 gallons an hour. At Nanuet and Orangeburg are other important springs. Fair supplies of water are obtained at Monsey, Spring Valley, and Orangeburg, at depths ranging from 40 to 180 feet. Most of the wells in the diabase or trap rock are shallow and the supply materially diminishes in dry seasons. In the sandstone the supply is more abundant and permanent and the water is usually soft.

Cretaceous.—The Cretaceous beds underlie the Quaternary drift at no great distance from the surface throughout the larger part of central and western Long Island and outcrop at a number of points along the north shore, and, more rarely, in the hills of the interior. Flowing wells of excellent water have been obtained at depths ranging from 100 to 700 feet below sea level.

Quaternary.—The Quaternary deposits of gravel, sand, and clay are, for the most part, of glacial origin and cover the hard rocks to a great extent. Their thickness in places amounts to 300 feet or more. Water permeates these unconsolidated materials very readily, and it is probable that the amount of well and spring water obtained from these deposits equals or even exceeds that derived from all other strata in the State. Springs are very abundant and some of them have large flows, which are utilized in many ways. Where not locally contaminated they furnish water of excellent quality, which is frequently used to supply village and town waterworks. Flowing wells are very abundant, especially in the southern part of the State, and yield from 50 to 600 gallons an hour. Thousands of dug and driven wells throughout the State derive their supplies from the Quaternary beds.

The largest supplies from the Quaternary deposits are obtained from the outwash plains and other deposits of Long Island. These plains consist largely of sand or fine gravel and are saturated with water below a moderate depth. Many towns and cities, including Brooklyn, obtain the whole or part of their supplies from shallow wells or springs that issue from the sands. Springs abound along both the north and south shores, and are found to a lesser extent in the moraine in the interior. Water from several of them is placed on the market.

PRODUCTION OF MINERAL WATERS.

If it were possible to estimate the amount and value of the water supply it would certainly rank as one of the most important of nature's products. During the past twenty years statistics have been obtained to show the amount and value of mineral waters produced and sold in the United States. For the year 1902, in New York State, 6,609,176 gallons were sold, valued at $1,299,037.[a] The bottling and shipping of water for drinking purposes in large cities and towns has become a considerable industry in many favorably situated localities. It is increasing very rapidly, but no statistics of amount or value are available.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

Commercial springs of New York.

County.	Town.	Owner.	Volume.	Character.	Use.
Allegany	Ceres	Ceres Mineral Spring Co.	Large flow	Mineral water	Medicinal.
Do	Whitesville	Whitesville Water Co	24 gallons per minute	Soft	Public supply.
Broome	Binghamton	F. D. Holcomb		Mineral water	Medicinal.
Do	Sanitaria Springs	S. A. Kilmer		do	Do.
Do	Vallonia Springs	James C. Sands	Large flow	do	Do.
Cattaraugus	Orlando	C. H. Bower		Soft	Power.
Do	West	E. E. Warn	1-inch pipe	Hard	Public supply.
Cayuga	Cayuga	Lucius Baldwin	Small flow	Mineral	Medicinal and table.
Do	Moravia		Very large	Soft	Public supply.
Do	Union Springs		do		Power.
Chemung	Breesport			Mineral	Medicinal.
Do	Chemung	Chemung Spring Water Co.	50 gallons per minute	Soft	Table water.
Chenango	Afton	Afton Waterworks	Large		Public supply.
Do	Bonney	S. Humphrey	½-inch pipe	Soft	Creamery.
Do	Oxford	Oxford Village	50 gallons per minute	do	Public supply.
Do	Smithville Flats		1-inch pipe	Slightly hard	Factory.
Columbia	Greendale	Brewer & Son	1½ gallons per minute	Soft	Table water.
Do	Lebanon	Columbia Hall Co	490 gallons per minute	Mineral	Medicinal.
Do	Pulvers	Charles Jacobia	Large flow	Soft	Table water.
Do	Stottsville	E. W. Cohen	do	Mineral	Medicinal.
Dutchess	Poughkeepsie	Mrs. E. J. Haynes	6-inch pipe	do	Do.
Erie	Williamsville	Ayers's estate	1 gallon per minute	do	Do.

Fulton	Johnstown	E. Frederick	8-inch pipe	Soft	Power.
Do	Perth	S. C. Hathaway	Large	do	Public supply.
Genesee	Batavia	Seven Spring Water Co.	3,700 gallons per minute	do	Do.
Do	Byron	Geo. Fisher	3 gallons per minute	Mineral	Medicinal.
Do	Byron Center	H. C. Norton	6-inch pipe	Hard	Cheese factory.
Do	Stafford	G. W. Scott	Very large	do	Fish ponds.
Greene	Grapeville	C. R. Palmer	do	Soft	Power.
Do	South Cairo	Geo. Duncan	50 gallons per minute	do	Public supply.
Herkimer	Fairfield	John McEvoy	Large	do	Do.
Do	Little Falls	L. A. La Rue	60 gallons per minute	do	Do.
Livingston	Avon	W. P. Wolfe	Small flow	Mineral	Medicinal.
Monroe	Fairport	W. A. Parce		do	Do.
Do	Parma			do	Do.
Oneida	Booneville	Booneville Mineral Spring Co.	4 gallons per minute	Soft	Medicinal, table.
Do	Cassville		Very large	Hard	Power.
Do	Franklin Springs	F. H. Suppe	5 gallons per minute	Mineral	Medicinal, table.
Do	do	A. W. Warner	14 gallons per minute	do	Do.
Do	Marcy	G. R. Wright	2-inch pipe	Soft	Manufacturing purpose.
Do	Verona	E. A. Groves	2 gallons per minute	Mineral	Medicinal, table.
Do	do	G. N. Lehr	do	do	Do.
Onondaga	Fayetteville	Fayetteville	Large	Hard	Public supply.
Do	Manlius	Village of Manlius	do	do	Do.
Ontario	Clifton Springs	Sanitarium	Very large	Mineral	Medicinal.
Do	Phelps	E. F. Marsh	Large	Hard	Public supply.

Commercial springs of New York—Continued.

County.	Town.	Owner.	Volume.	Character.	Use.
Orange	Port Jervis	L. L. Blackman			
Oswego	Fulton	Great Bear Water Co	250 gallons per minute	Slightly mineral	Table.
Do	Oswego	Nelson Morrow			
Otsego	Cherry Valley	L. W. Thompson			
Do	Richfield Springs	T. R. Proctor	Very large	Mineral	Medicinal.
Rensselaer	Hoosick Falls	Bratt's estate	200 gallons per minute		Power.
Rockland	Nanuet	W. Davidson		Mineral	Medicinal.
St. Lawrence	Massena		Large	do	Do.
Saratoga[a]	Ballston				
Do	Gurnspring	C. E. Roods	1 gallon per minute	Mineral	Do.
Do.[a]	Saratoga				
Do	Wayville	T. C. Luther	2-inch pipe	Mineral	Do.
Schoharie	Sharon Springs	J. H. Gardner & Son	200 gallons per minute	do	Do.
Schuyler	Montour Falls	C. D. Clauson	1½ gallons per minute	do	Do.
Do	Watkins	Glen Springs Co		do	Do.
Seneca	Canoga	S. T. Allen	Large	Hard	Power.
Steuben	Canisteo	Waterworks Co	100 gallons per minute	Slightly hard	Public supply.
Sullivan	Willowemoc	Elias Depuy	8-inch pipe	Soft	Manufacturing.
Do	Livingston Manor	Charles Ellis		do	Creamery.
Tioga	Apalachin	M. S. Olmstead	12 gallons per minute	Mineral	Medicinal.
Do	Halsey Valley	Ira Hoyt	Very large	Soft	Power.
Tompkins	Dryden	S. S. Nivison	Large	Mineral	Medicinal.
Do	Slaterville		6 gallons per minute	do	Do.

Ulster	Clintondale	S. P. Thorn	50 gallons per minute	do	Medicinal, table.
Do	Ellenville	F. S. Benedict	100 gallons per minute	Soft	Table water.
Warren	Adirondack	C. H. Van Brunt	120 gallons per minute	do	Do.
Do	Bolton Landing	Green Island Improvement Co.	Very large	Slightly hard	Public supply.
Do	Chestertown	F. Velter	6 gallons per minute	Soft	Do.
Washington	Cambridge	Cambridge Waterworks Co.	2,000 gallons per minute	do	Do.
Do	Fort Edward	Brewing Co	Large	Mineral	Medicinal.
Do	Whitehall		Small	do	Do.
Westchester	Bronxville	W. V. Lawrence	Large	Soft	Table water.
Wyoming	Arcade	Waterworks Co	2,000 gallons per minute	Slightly hard	Public supply.
Do	Bliss	Chas. Walton	Very large	Soft	Do.
Do	Eagle	J. G. Mitchell	do	Hard	Power.
Do	Pearl Creek	W. A. Hawley	17 gallons per minute	Soft	Milk station.
Yates	Branchport		do	Mineral	Medicinal.

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[a] Mineral waters are now almost wholly obtained from deep wells.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 26–41.

Mineral resources of New York, by F. J. H. Merrill: Bull. New York State Mus., Vol. III, 1895.

Artesian well prospects in the Atlantic Coastal Plain region, by N. H. Darton: Bull. U. S. Geol. Survey No. 138, pp. 22–38.

Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, 1902, pp. 15–19.

New York [well and spring records], by F. B. Weeks: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, 1904, pp. 169–206.

The new artesian well supply at Ithaca, N. Y., by Francis L. Whitney: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1905, pp. 55–64.

Water resources of the Fort Ticonderoga quadrangle, Vermont and New York, by T. Nelson Dale: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1905, pp. 126–129.

Water resources of the Taconic quadrangle, New York, Massachusetts, and Vermont, by F. B. Taylor: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1905, pp. 130–133.

Water resources of the Watkins Glen quadrangle, New York, by R. S. Tarr: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, pp. 134–140.

NEW JERSEY.

By G. N. KNAPP.

TOPOGRAPHIC PROVINCES.

New Jersey has been divided into four provinces, or zones, on the basis of its physiographic features. These provinces are indicated on the accompanying sketch map (fig. 18) and are designated (1) the Appalachian, (2) the Crystalline Highlands, (3) the Piedmont, and (4) the

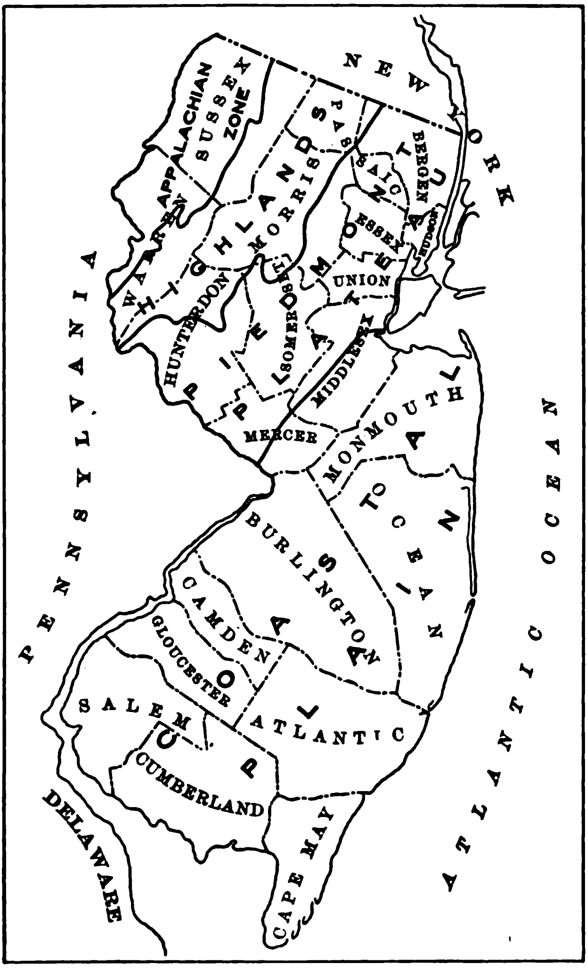

FIG. 18.—Subdivisions of New Jersey governing the appearance of underground water.

Coastal Plain.[a] The surface features of these several provinces, by reason of which they differ the one from the other, are in large measure simply the outward manifestations of geologic characters, structural and lithologic, which are inherent in the terranes of the different provinces and which have found topographic expression through subaerial and stream degradation.

As might be expected the underground or deep waters of the State sustain relations that differ in the different provinces and that are more or less characteristic of them. Rocks so different in structure and lithologic character as to give rise to topographic features that are as distinct and characteristic as are those of the several provinces might be expected to profoundly affect the disposition of underground water. This is, in fact, found to be true, and this subdivision of the State is regarded as the one best adapted to a general discussion of the deep waters.

GEOLOGY AND WATER SUPPLY.

APPALACHIAN PROVINCE.

The Appalachian province, or zone, is the northern extension in New Jersey of the great Appalachian mountain system. It is essentially coincident with the great Kittatinny Valley and Kittatinny Mountain.

The rocks consist of limestone, slates, conglomerates, sandstones, and quartzites, strongly infolded in anticlines and synclines whose axes run northeast and southwest. These primary folds have been more or less faulted and modified by dikes and other late intrusions. The whole series has been profoundly eroded, plains of degradation have been developed, truncating the old folds, and later broad, deep valleys have been developed parallel to the main axes of the folds. In these broad valleys the softer beds, such as limestones and shales, stand at angles that range from vertical to horizontal and dip in various directions. The ridges or mountains that inclose these valleys consist of the harder rocks, viz: Conglomerates, quartzites, slates, and sandstones, which rise more or less abruptly to heights of 1,000 or 1,500 feet above the valleys. The beds themselves stand at various angles, commonly approaching verticality.

The various beds of the Kittatinny Valley have in large measure lost through metamorphism whatever porosity they may once have had. The sandstones have become quartzites, more or less dense; the conglomerates have suffered a like modification, reducing their porosity to a minimum, and the other rocks have undergone similar changes, tending to increase their density. The rocks have, however, been fractured at various times, so that joints occur more or less abundantly throughout the beds, admitting water to unknown depths. In the limestones solution has developed cavities and more or less definite underground courses.

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[a] New Jersey Geol. Survey Final Report, Vol. IV, Physical Geography, 1898.

The rocks then of the Appalachian province are relatively impervious and do not carry a large volume of water. The water that penetrates deeply does so by virtue of secondary structures and other modifications that do not stand in close relation to the primary structure.

Therefore a knowledge of the structure, which is regular enough to be determined with considerable definiteness, is not of so much service in locating successful wells as might be expected. The water seems capricious in its occurrence. The data available, however, show but few deep wells in this province—too few to be made the basis of final conclusions, so that the great Kittatinny Valley has yet to be thoroughly tested for its available deep water supply.

CRYSTALLINE HIGHLANDS PROVINCE.

The Crystalline Highlands, as the name suggests, consists more largely of crystalline rocks—granites, schists, and gneisses. The great structural lines of the province run northeast and southwest, like those of the Appalachian zone, but this region has been subject to more profound metamorphism and the beds have been repeatedly broken and faulted at widely separate time intervals. Intrusive rocks have been injected as dikes and masses at different times, secondary structures have very generally destroyed or replaced the original ones, and along with this have gone replacement and interchange of the mineral constituents of the rocks.

In the Crystalline Highlands, therefore, the structure is too complex and too indefinite to aid one in a practical way in predicting the result of wells, and the terranes contain no well-defined porous beds that in a true sense can be called water bearing in contradistinction to others. The rocks, however, as a whole, are more generally permeated by water than in the Appalachian zone, so that wells put down indiscriminately give a larger percentage of satisfactory wells in the former than in the latter region. We know from the numerous iron mines scattered through the Highland region that the permeation of these old crystallines by water, while very general, is by no means uniform; for some mines encounter large volumes of water, greatly to their detriment, whereas others are comparatively dry. The relation, if any, that exists between the local rock structure or the depth of the mine and the volume of water encountered is not apparent.

In the Highland province there are some areas that form notable exceptions to the structure above outlined; such, for instance, as the Green Pond mountain belt, where the rocks and structure are analogous to the infolding of the Appalachian zone. In these exceptional areas the deep waters behave much as they do in the Kittatinny region.

The numerous streams, as yet not polluted, afford an abundance of excellent water. This, together with the cost of drilling in such hard rock, i. e., $5 to $10 a foot, has heretofore limited the number of deep wells.

This province, however, is being invaded by suburban homes and country residences, and we may expect that in the near future more deep wells will be bored.

PIEDMONT PROVINCE.

The Piedmont province is essentially the area of the Newark system. The Newark consists of three series of beds which, from base upward, are the Stockton, the Lockatong, and the Brunswick. The Stockton consists of light-colored sandstones and conglomerates, more or less arkose, interbedded with a few red shales. It is the most permeable series of the Newark system. The Lockatong consists chiefly of flagstones and argillites, and is relatively impervious. The Brunswick series consists chiefly of shales, but includes also many beds of sandstone. It is less permeable than the Stockton.

The Newark system is traversed by a number of irregular faults whose throw is nearly sufficient to repeat the entire system at each successive fault. The prevailing dip of the beds is west and northwest, but more or less local warping and tilting that accompanied the faulting gave the beds many local variations in dip and strike. The structure of the Newark is further complicated by an irregular system of volcanic intrusive sheets and trap dikes that cut across the bedding at various angles.

The faulting of the Newark in a way to repeat the succession is a slight advantage in some situations, since it makes the Stockton beds more readily available for artesian water at some localities than they otherwise would be, but in other situations the faults cut off the supply entirely, so that the advantage in one locality is in large measure offset by the disadvantage in the other. One familiar with the complex structure of the Newark can forecast the chances of obtaining artesian water at given points in the Piedmont province; but it would be difficult for one unfamiliar with the structure to make such forecasts.

The Newark system is thoroughly cut up by two or more [illegible] of deeply penetrating joints, whose planes are nearly ver[illegible] and intersect one another at various angles. It is thought that the [illegible] wells in the Newark draw their supply from these joints and [illegible] more largely than from the water that penetrates along the [illegible] ding planes. Nearly one half of the northern end of the P[illegible] province is, however, mantled by glacial drift which conceal[illegible] of the minor details of the Newark structure. This not infre-

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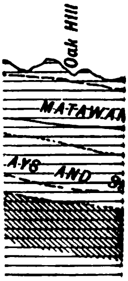
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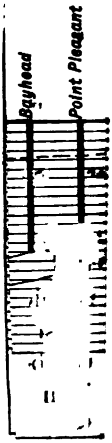
Bayhead
Point Pleasant

quently entirely precludes the possibility of calculating closely the chances of artesian water at certain points.

Of the three provinces thus far considered, the Piedmont carries vastly more deep water than either of the others. Moreover, the water is found in rocks that are drilled with comparative ease, and the chances of obtaining it can be foretold with much definiteness. Furthermore, the Piedmont is, by virtue of its geographic position, the most important of the three, since it includes what is and what always will be the most densely populated part of the State, in which the water supply will always be a paramount question.

COASTAL PLAIN PROVINCE.

The Coastal Plain differs from the three northern provinces in nearly every essential feature. First, it includes an area greater than the combined area of the other three provinces; second, as compared with the other provinces it is flat, there being no mountains and the maximum relief being less than 400 feet; third, its structure is of the simplest sort, for it consists of a succession of beds lying one upon the other in a simple monocline that dips seaward, the uppermost or youngest bed lying farthest southeast, and each successively older and lower bed reaching a little farther northwest; fourth, there have been no faults or folds of sufficient magnitude to appreciably affect the general structure; fifth, the beds are unconsolidated sands, clays, marls, and gravels, and lie in essentially the same position in which they were deposited; sixth, the terranes have not suffered any metamorphism that has appreciably affected their permeability to water.

The Coastal Plain province falls into two great geologic divisions or subprovinces, viz, the Cretaceous and the Tertiary. The Cretaceous occupies a relatively narrow belt that extends across the State, while the Tertiary covers the remainder of the province.

The Cretaceous has three major divisions, which, reckoned from base upward, are the Raritan, the Clay Marl series, and the Marl series. The Clay Marl series corresponds approximately but not exactly to the "Matawan" of the later nomenclature, while the Marl series includes approximately but not exactly the Monmouth, Rancocas, and Manasquan of later nomenclature.

The Raritan, though carrying important water beds at different stratigraphic horizons, does not admit of subdivision. The Clay Marl series, on the other hand, is readily subdivided into five beds, the lower two of which are impervious marl and clay and serve as a cover to the Raritan water-bearing sands. The stratum next above is a sand bed, which is 100 feet thick to the northeast, where it is an important water horizon; toward the southwest it pinches out entirely and disappears along the strike. Above this is an impervious marl and clay.

Next comes a sand bed 100 feet thick to the southwest, where it is an important water horizon. To the northeast it becomes less important, partly by reason of its decrease in thickness in that direction and partly by a decrease in permeability.

The Marl series, like the Clay Marl series, is readily subdivided into five beds, the lower of which corresponds to the Lower Marl, approximately the "Navesink." Above this is the Red sand (Redbank). Toward the northeast it is a sand bed 100 feet thick, but toward the southwest it pinches out and disappears along the strike. Next above is the lower portion of the old Middle Marl bed—the marl proper. It constitutes a part but not all of the Sewell. Still higher is the Lime and "Yellow" sand; the upper part of the old Middle Marl bed, including the "Vincenttown" and more. This is an important water horizon all across the State. The top bed is the Upper Marl, a part of which is Eocene. It is the impervious cover to the preceding.

The second subprovince of the Coastal Plain, the Tertiary, is divided into two formations, the Kirkwood (Miocene), and the Cohansey (Pliocene?). The lower bed is the Kirkwood. It carries water-bearing sands at several different stratigraphic horizons. It is an important source of water at Atlantic City and at points farther south along the beach. Next higher is the Cohansey formation. It carries water at several different stratigraphic horizons and rivals the Kirkwood as a source of artesian water along the beach.

The structure of the Coastal Plain is extremely simple. The outcrop of the beds is known in great detail. Their dip is known, or is readily determinable, and the altitudes of the various beds can be closely estimated at all points. Still the predicting of artesian water at any given point is not a simple mathematical proposition. Two chief difficulties are experienced in predicting the results of wells: First, the thickening of the beds down the dip, seaward, has not been worked out in detail for individual beds; second, the permeability of the beds is a variable factor, whose exact value is yet to be determined.

In the following table the results of borings at a large number of localities on the Coastal Plain are presented:

Summary of well statistics in the more important of the Coastal Plain localities.

[Compiled from tables of N. H. Darton.[a]]

Locality.	Range of depth.		Range of capacity per minute.		Geologic horizons of water.
	From—	To—	From—	To—	
	Feet.	*Feet.*	*Gallons.*	*Gallons.*	
Asbury Park	383	1,330	20	500	Lower marl, Matawan, Raritan.
Atlantic City	118	1,398	0	400	"Diatom bed," Cretaceous, Chesapeake.
Atlantic Highlands	108	480	80	250	Matawan, Raritan.
Barnegat Landing	....	120	....	....	
Bayhead	....	710	....	....	Lower marl.

[a] Bull. U. S. Geol. Survey, No. 138, pp. 42–48.

Summary of well statistics in the more important of the Coastal Plain localities—Cont'd.

Locality.	Range of depth.		Range of capacity per minute.		Geologic horizons of water.
	From—	To—	From—	To—	
	Feet.	*Feet.*	*Gallons.*	*Gallons.*	
Bayside		190	0		Unknown.
Beach Haven	430	575	10	125	Bed C, Atlantic City; bed E, Atlantic City.
Berkeley Arms		470		60	960 feet at Atlantic City(?).
Bordentown	119	195		Many.	Raritan, basal Raritan.
Bridgeton		90	0		Post-Chesapeake.
Brigantine		798		100	800 feet at Atlantic City.
Burlington	135	253	0	25; plenty.	Raritan.
Camden	112	152	16	150	Basal Raritan.
Cape May City		224		75	Upper Chesapeake. Unknown.
Cape May Point		360		Fair supply.	Upper Chesapeake.
Clayton (6 wells)		105		Each, 150	Post-Chesapeake(?).
Collingswood		196		Fair supply.	Raritan.
Columbus	156	356		10; fair supply.	Raritan, basal Matawan.
Crab Island		520		Satisfactory.	*b*
Englishtown		210	0		Matawan.
Fellowship		131		Many.	Do.
Fifields		397	0		Chesapeake.
Freehold	172	322	25?	250; unsatisfactory.	Lower marl, Matawan.
Glassboro		511	0	100	Post-Chesapeake, Matawan.
Gloucester	102	270	100	650	Basal Raritan, basal Matawan, Raritan.
Great Sedge Island		320		100	
Greenwich		690	0		Lower marl.
Harrisia		375			
Harrisonville		122		Plenty.	Middle marl.
Hartford		187	0		Matawan.
Harvey Cedars	240	500		100	
Hightstown	201	500	12	70	Matawan, Raritan, basal Raritan
Holmdel		601	0		Raritan.
Jamesburg		481		52	Do.
Keyport		242		12	Do.
Lake Como		585			Lower marl.
Lakewood		475			Do.
Longport		803		180	Bed G, Atlantic City.
Lucaston		110			Middle marl.
Mantoloking	175	922			Bed C, Atlantic City, lower marl, Matawan.
Maple Shade		375			Basal Raritan.
Marlton	102	365	0	20; fair to plenty.	Redbank, lower marl(?), Matawan.
Matawan		100			Matawan.
Mays Landing	100	176	7	25	428 feet, Atlantic City(?), bed C, Atlantic City(?).
Mechesatankin Creek		158		Unsatisfactory.	
Medford	126	183		Plenty; satisfactory; 200.	Redbank, lower marl,

Summary of well statistics in the more important of the Coastal Plain localities—Cont'd.

Locality.	Range of depth.		Range of capacity per minute.		Geologic horizons of water.
	From—	To—	From—	To—	
	Feet.	*Feet.*	*Gallons.*	*Gallons.*	
Millville	150	160		Satisfactory.	
Monmouth Beach		380			Matawan.
Monmouth Park		385		75	Do.
Moorestown		150			Basal Matawan.
Mount Ephraim		130		Satisfactory.	Basal Matawan(?).
Mount Holly		675			Raritan.
Mullica Hill		102			Redbank.
Ocean Beach	480	485	25	50	Lower marl.
Ocean City	760	800		140	Chesapeake diatom bed.
Ocean Grove	420	1,134		40	Lower marl, Matawan.
Pavonia	112	174		275	Raritan, basal Raritan, crystalline rock.
Perth Amboy	130	470	0		Basal Raritan, 70–470 feet in gneiss.
Pleasant Mills	156	201		500; unsatisfactory.	658 feet at Ocean City(?), Chesapeake.
Port Monmouth		+100		Few.	Matawan.
Point Pleasant		806		45	Do.
Port Norris		200		1	
Port Republic		151			428 feet, Atlantic City(?).
Quinton	248	275		55	Redbank.
Rancocas		124			Basal Matawan.
Redbank		230		165	Lower marl, Matawan.
Riverside (8 wells)		200	18	Each; 40	Raritan(?).
Rumsen Neck		210		60	Matawan.
Runyon Station		160	0		
Sayreville		976		Many.	Basal Raritan, 80,976 feet in gneiss.
Sea Girt		755		50	Matawan.
Seabright	125	258	55	210	Lower marl, Matawan.
Sea Island City		380		30	Above diatom bed.
Seven Islands	408	585	60	70	Bed E, Atlantic City; bed C, Atlantic City(?).
Sewell		420		25	Basal Matawan.
Shrewsbury		200	0		Lower marl.
South Amboy		105			Basal Raritan.
South Beach Haven		425		10?	Bed C, Atlantic City.
Spring Lake		465		Many.	Lower marl.
Stockton	116	130		875	Basal Raritan, Raritan.
Straight Creek		100		Many.	
Trenton		160		Many; 200	Post-Chesapeake(?). Basal Raritan.
Vineland		205		20	Post-Chesapeake.
Waretown		280		20	Bed E, Atlantic City.
Wenonah	196	341			Basal Matawan, Matawan.
Weymouth		106	52	70	Bed C, Atlantic City(?); 650 feet at Atlantic City(?); bed C Atlantic City(?).
Wildwood	215	931	10	300; unsatisfactory.	Upper Chesapeake, 240 feet below great diatom bed; in great diatom bed.
Winslow	135	145	20	40	Chesapeake, 960 feet at Atlantic City (?).
Woodbury	113	163		8	Matawan, basal Matawan.
Woodstown	139	776		360	Basal Matawan, Redbank, Raritan.

SUMMARY OF WATER RESOURCES.

The accompanying table brings into prominence many important relations and suggests many more.

Distribution of wells by provinces.

	Appalachian.	Crystalline Highlands.	Piedmont.	Coastal Plain.
Area in square miles	547.0	945.0	1,463.0	5,099.0
Approximate population	24,201.0	76,029.0	1,222,586.0	495,072.0
Average number of people per square mile	44.2	80.4	836.3	97.7
Maximum density of population per square mile per township	1,590.0	8,475.0	22,560.0	14,492.0
Minimum density of population per square mile per township	23.0	26.0	37.0	6.0
Records of wells	23.0	31.0	547.0	998.0
Average number of square miles to each well	24.0	30.0	26.0	5.0

It will be noticed that of the 1,600 wells catalogued, nearly 1,000 are in the Coastal Plain province. These range in depth from 50 to 2,300 feet and probably 90 per cent of them are of the true artesian type—that is, they draw their water from beds whose catchment area is remote, and the water in the wells rises nearly or quite to the surface, and frequently above the surface. Of the 550 wells in the Piedmont Plain very few are of the true artesian type. They range in depth from 50 to 2,300 feet. Many of them yield large volumes of water and a few of them flow, but, as before suggested, they probably draw their supplies largely from the joints and the secondary structures of the rocks. Of the 50 or 60 wells in the two northern provinces, only a few are truly artesian. They are practically all simply deep reservoir-like holes into which water percolates from innumerable joints and fissures at all horizons. While the gathering ground of such waters may be remote from the wells, they belong in a different class from those of the Coastal Plain. It will be remembered that the wells here catalogued are the ones of which records have been obtained, and not the actual total number of wells in these provinces. There are undoubtedly many wells of which no records have been procured.

The Appalachian and Crystalline provinces are relatively sparsely settled. In them springs abound, and mountain streams, proverbially wholesome and as yet unpolluted, are numerous and well distributed, so that the demand for deep wells is not pressing.

DISTRIBUTION OF WELLS AND POPULATION.

The Piedmont area includes two fairly distinct subprovinces. The first, including the northeast part of the area, in the vicinity of Essex and Hudson counties, is occupied by numerous cities, large and small, many of which are manufacturing centers, while the second, in the southwest portion, in the vicinity of Somerset County, is dominantly an agricultural region. The first of these subprovinces includes about one-fifth of the area of the Piedmont province and contains about nine-tenths of its population, the remaining one-tenth of the population being scattered over the southwestern four-fifths of the province. Of the 550 wells in the Piedmont province more than 500 occur in the densely populated region in its northeastern portion and the water, for the most part, is used for manufacturing purposes.

In the Coastal Plain province the densely populated districts are distributed around its periphery, the interior being more sparsely settled. The distribution of the artesian wells stands in fairly definite relation to the density of population. Along the seashore are many thriving towns and cities whose function is almost wholly that of ministering to the service of those in quest of health, recreation, and pleasure. These communities, while not absolutely dependent on artesian wells for their water, find them the most satisfactory available source of supply, and hence a large percentage of the wells are found along the coast.

The north and northwest border of this province, which is approximately the outcrop of the Cretaceous terranes, finds its interests divided between agriculture and manufacture. Artesian wells are abundant in this region but are not so deep as those along the coast, and are accordingly less expensive. They serve both the manufacturing and the agricultural interests. In fact, the distribution of the artesian wells is determined, first, by the availability of the water; second, by the density of the population, and third, by the character of the population.

MINERAL SPRINGS.

Sixteen mineral springs in New Jersey reported sales of water in 1902, and many more are the site of pleasure resorts of more or less importance. The aggregate production for the year is given as 360,900 gallons, with a value of $41,875. The springs reporting are as follows:[a]

Alpha Spring, Springfield, Union County.
Beacon Mountain Spring, Denville, Morris County.
Beech Springs, near Woodbury, Gloucester County.
Fowler's Deep Rock Artesian Well, Allwood, Passaic County.
Hatawanna Spring, Budd Lake, Morris County.
Holly Springs, Swedesboro, Gloucester County.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

Indian Kalium Spring, Gloucester, Camden County.
Indian Spring, near Rockaway, Morris County.
Kalium Springs, Collingswood, Camden County.
Oakland Vernam Spring, near Oakland, Bergen County.
Pine Lawn Spring, Hohokus, Bergen County.
Trinity Springs, Ridgefield, Bergen County.
Turtle Hill Spring, Passaic, Passaic County.
Washington Mountain Spring, Pennington, Mercer County.
Washington Rock Spring, Warrenville, Somerset County.
Watchung Spring, Plainfield, Union County.

PRINCIPAL PUBLICATIONS.

[Artesian wells of New Jersey], by Lewis Woolman and others. A large number of references and reports on the artesian wells of New Jersey are contained in the New Jersey Geological Survey Reports, beginning with the year 1857 and extending down to the present time. (See indexes of individual reports.)

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 42–43.

Artesian well prospects in the Atlantic Coastal Plain region, by N. H. Darton: Bull. U. S. Geol. Survey No. 138, 1896, pp. 39-115.

Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton. Water-Supply and Irrig. Paper U. S Geol. Survey No. 61, 1902; pp. 12-14.

Water resources of the highlands of New Jersey, by Laurence La Forge: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1905, pp. 141-155.

PENNSYLVANIA.

By M. L. Fuller.

TOPOGRAPHY.

There are three distinct topographic belts in Pennsylvania: (1) A southeastern belt, whose northern boundary starts about 10 miles southeast of Easton and passes southwestward, just south of Reading and Harrisburg, to a point a few miles west of Gettysburg; (2) a central belt, lying north and west of the first, whose northern boundary reaches from the northeastern part of the State westward and southwestward, past Williamsport, Lock Haven, and Altoona, to the southeastern portion of Somerset County; and (3) a northwestern belt which embraces the entire northern and western portions of the State. (See fig. 14.)

The eastern belt, known as the Piedmont Plateau, is in general of low elevation, and consists of a broadly rolling surface with few high hills. The central belt, constituting the Appalachian Mountains and Valley, consists of a large number of long, straight, or gently curving ridges, alternating with deep valleys, the widest of which is the Cumberland or Shenandoah. Many of these ridges rise to altitudes ranging between 1,500 and 2,500 feet. The third belt, known as the Allegheny Plateau, is a broad surface, cut throughout its extent by streams which now flow in deep and frequently canyon-like valleys. A few ridges rise above the common level of this upland, but the plateau has a general southwestward slope, and varies in altitude from about 2,000 feet in the northern portion of the State to approximately 1,200 feet in the southwestern portion.

GEOLOGY.

The geologic divisions correspond in general with those of topography; in fact, the geology has governed the character of the topography throughout the State. The southeastern topographic belt, or Piedmont Plateau, is underlain largely by crystalline rocks which have been very evenly eroded and consequently present few conspicuous topographic features. Along the northern border of this belt is a band of soft Triassic shales and sandstones of a topography similar to that of the adjoining crystalline area. The continuity of the belt is, however, broken by a series of folded Cambrian and Silurian quartzites and limestones that extend from near Trenton westward across the Susquehanna to the southeast corner of Adams County. The cities of York and Lancaster are located in this belt, while Phœnixville, Norristown, and Trenton lie just outside its borders.

The rocks of the middle topographic belt, which is characterized by prominent ridges, consist mainly of strongly folded beds of Cambrian, Silurian, and Devonian age, but the folded rocks of the anthracite coal basin and of the Broadtop coal basin in the south-central portion of the State are of Carboniferous age.

The rocks of the remaining or plateau portion of the State are Devonian and Carboniferous, the former constituting the surface in the northern and northeastern portion of the State and the latter in its western part. The rocks of this belt are characterized in general by very moderate folding, although the rocks of Laurel Hill and other ridges in the southwestern portion of the State show high dips. The folds generally decrease uniformly in magnitude as their distance from the Appalachian Front increases, until in the northwestern part of the State only slight and irregular undulations can be detected. It is along the crest of the anticlines that the lower Devonian rocks are brought to the surface in the northern part of the State.

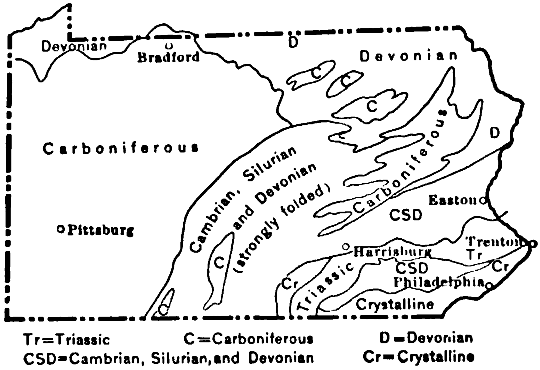

FIG. 19.—Geologic subdivisions of Pennsylvania.

SOURCES OF WATER SUPPLY.

STREAMS AND LAKES.

By far the larger number of the streams of Pennsylvania rise either in the mountainous regions of the Appalachian belt or in the highlands of the Allegheny Plateau. In general they have their sources in rugged forest-covered areas remote from habitations, and for considerable distances flow with their original purity through thinly populated districts. Even within a few miles of some of the large cities supplies from unpolluted streams may be procured. The waters of the larger streams, however, are generally polluted and unsafe for domestic use except where they are subjected to some process of purification. There are no large natural lakes within the State, but a few small ponds are found in depressions in the drift on some of the flat mountain tops and elsewhere in its northern portion. These ponds are seldom of any value as a source of water supply.

WELLS.

The drift.—The glacial drift in Pennsylvania is confined to the northern half of the State. The glacial boundary enters from the east at a point not far from Easton and passes northwestward to the New York line not far from Bradford. Here it leaves the State for a few miles, but soon turns south again, reenters the State and passes southwestward to a point a few miles north of Ohio River at the western border of the State.

In the area south of this line the loose materials at the surface, except in the river and stream valleys, consist of fragments of rock which have been broken up to form a stony soil under the action of the weather. North of the glacial boundary this residual soil has been reworked by glacial action and mixed with foreign material brought down from the north, the whole being left as a heterogeneous stony mantle, known as till, covering the surface. In addition to the till many deposits of gravel or sand were laid down in the valleys by streams flowing from the glacier.

The till usually contains a considerable percentage of clay and is not usually a satisfactory source of water. Nevertheless it furnishes small supplies to wells at many points throughout the northern portion of the State. The water follows rather definite courses through the material and its occurrence can not always be predicted. Its amount is almost always small, but it is of very fair quality. Springs are common, but are usually small and of little economic value.

Stream deposits.—In the stream deposits, which consist largely of gravel and sand, great quantities of water are stored, especially in the larger river valleys. The great absorptive power of these materials is strikingly shown by their rapid absorption of the mountain streams which emerge upon them. Wells driven but a few feet into such deposits often find abundant supplies. Their waters are almost always of excellent quality if taken at sufficient depth to be out of the zone of pollution from the surface.

Crystalline rocks.—The crystalline rocks consist of gneisses and similar granitic rocks. In general they carry but little water, for their porosity is small and they are not characterized by bedding planes that offer easy passages for water. These rocks are, however, cut by more or less vertical joints which admit considerable quantities of water under favorable conditions. Wells drilled in the crystalline rocks, especially in Philadelphia and vicinity, have frequently obtained moderate to good supplies at depths of from 100 to 300 feet. As a rule, wells that fail to obtain a supply within 300 feet of the surface will not afford much water at greater depths. Springs are relatively few in number and small in size, and are seldom used except in the vicinity of the large cities, where they furnish considerable quantities of water for table use.

Triassic rocks.—The Triassic rocks, the extent of which has already been indicated, consist of shales and soft sandstones, frequently stained red by iron oxide. The sandier beds contain a large quantity of water, a cubic foot sometimes holding a quart or more. Many wells have been drilled into these rocks in the towns scattered along their outcrop and considerable supplies have been obtained in some places. The waters, however, are liable to be strongly mineralized and in some cases it is impossible to use them in boilers. Springs occur in the Triassic rocks, but are not commonly important.

Cambrian and Silurian rocks.—The Cambrian and Silurian rocks consist of quartzites, limestones, and shales. They are characterized throughout, as has already been indicated, by strong folds, the rocks in many instances being almost on edge. The outcrops of the formations generally occur, therefore, as rather narrow, straight, or gently curving bands, although belts of considerable width are found where the folds are more open.

The true quartzites are dense, compact, and nonporous, exhibit very little jointing, and are frequently destitute of recognizable bedding planes. Under such conditions they are practically destitute of water. Some of the beds, however, especially the Medina and Oriskany sandstones, are less dense, and carry water which issues as fine large springs where the outcrops are favorable. The limestones, which include the Trenton and Lower Helderberg, are rather dense and carry water only in solution channels. For this reason the finding of water in them is uncertain, and they are, therefore, rarely a source of supply, although in some cities and towns deep wells have obtained satisfactory supplies from these rocks. There are many fine springs along the edges of the limestone areas, but in the central portion of the outcrops cisterns are mainly relied upon for water for domestic purposes.

The shales carry some water in their bedding planes and in sandy interbedded layers. Small springs are fairly common, and in the less strongly folded portions wells usually obtain moderate supplies.

Devonian rocks.—The Devonian rocks, as already indicated, occur to some extent infolded with the Cambrian and Silurian rocks, and are also brought to the surface by gentle folds in the northern portion of the State. They consist largely of shales, although sandstones are frequently present, especially in the subdivision of the Devonian known as the Catskill. Limestones are occasionally present. Springs are numerous in the areas where the Devonian shales and limestones outcrop, but they are small as compared with the springs of the Cambrian and Silurian areas. They afford, nevertheless, pure supplies for a large number of the inhabitants in the areas in which they occur. Wells also generally obtain fair supplies. In the synclines or basins flowing water is not uncommonly obtained by the deeper wells, but, because of the abundance of spring water and of water in the drift, deep wells are not often sunk.

Carboniferous rocks.—The Carboniferous rocks consist of a thick series of sandstones, shales, limestones, and coals. The limestones are generally only a few feet thick, but some of the beds may run up to 50 or 100 feet, or even more. They are not prominent water bearers, although small supplies are almost always obtained either at their upper surfaces or from some of their bedding or joint planes.

The Carboniferous shales, like the Devonian, frequently carry water along their bedding planes and in their interbedded sandy layers, but though giving rise to a considerable number of springs and furnishing supplies for many shallow wells, they are not conspicuously water bearing.

Water is frequently found associated with the coals, but is almost always highly charged with ferrous sulphate, resulting from the decomposition of the pyrite in the coal. Sandstones are often of great thickness and are fairly open and porous. Where above drainage level they commonly carry relatively little water, but below this level they are often saturated, and drilled wells penetrating them generally obtain good supplies. Where the rocks lie a considerable distance below the surface, however, the fresh water is liable to be replaced by salt water or by oil; hence deep wells are sometimes of little value as sources of water supply. Flowing water is frequently obtained in the synclines or basins and elsewhere where the conditions are favorable, but the water will seldom rise more than a few feet above the surface, and pumping is almost universally necessary to raise it for industrial uses. In general, fresh waters in the Carboniferous and Devonian rocks are found within 500 feet of the surface. Below this point the rocks are in some places entirely destitute of water, and in others carry salt water as indicated above.

Coastal Plain deposits.—The eastern portion of Philadelphia is underlain by Coastal Plain formations, consisting of the lower beds of the Raritan-Potomac deposits. These beds are water bearers and have been tapped by a number of wells in the city.

MINERAL SPRINGS.

The waters of Pennsylvania, except those of the Triassic area, of the limestones, and those associated with coals, are usually low in mineral matter. There are, however, scattered throughout the State a number of deep-seated springs the waters of which are mineralized. Many of these mineral waters are bottled and sold commercially, and resorts of importance have been developed about others. The mineral springs are not confined to any one class of rocks, but are found in all of the types described. The following springs reported shipments in 1902:[a]

Artesia Spring, Harrison Valley, Potter County.
Bedford Chalybeate Spring, Bedford, Bedford County.
Bedford Mineral Springs, near Bedford, Bedford County.
Black Barren Mineral Spring, Pleasant Grove, Lancaster County.
Buena Vista Springs, Buena Vista, Franklin County.
Charmian Mineral Spring, Charmian, Franklin County.
Cloverdale Artesian Lithia Spring, Newville, Cumberland County.
Corry Artesian Mineral Spring, Corry, Erie County.
Cresson Springs, Cresson, Cambria County.
De Vita Mineral Springs, Cambridge Springs, Crawford County.
East Mountain Lithia Well, near Factoryville, Wyoming County.
Ephrata Mountain Crystal Spring, near Ephrata, Lancaster County.
Glen Summit Spring, Glen Summit, Luzerne County.
Gray Mineral Spring, Cambridge Springs, Crawford County.
Imperial Spring, Angelica, Berks County.
Korrylutz Well, Corry, Erie County.
Magnesia Spring, Cambridge Springs, Crawford County.
Malvern Spring, Malvern, Chester County.
Parker Mineral Spring, Gardeau, McKean County.
Pavilion Spring, South Mountain, Wernersville, Berks County.
Petticord Mineral Spring, Cambridge Springs, Crawford County.
Pulaski Natural Mineral Spring, Pulaski, Lawrence County.
Rennyson Tredyffrin Spring, Rennyson, Chester County.
Ross-common Springs, Windgap, Monroe County.
Saegertown Mineral Spring, Saegertown, Crawford County.
Sizer Mineral Spring, Sizerville, Cameron County.
Spruce Hollow Mineral Spring, near Northumberland, Northumberland County.
The J. W. Lang Mineral Well, Venango, Crawford County.
Tuckahoe Mineral Springs, Northumberland, Northumberland County.
Whann Alkaline Lithia Mineral Springs, near Franklin, Venango County.
White House Spring, Neversink Mountain, Reading, Berks County.

The aggregate amount of water sold in 1902 is given as 4,567,260 gallons, valued at $1,124,532.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

PRINCIPAL PUBLICATIONS.

Mineral Springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 44–49.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton: Bull. U. S. Geol. Survey No. 138, pp. 115–117.

Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, 1902, pp. 29–42.

Water resources of the Philadelphia district, by F. Bascom: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 106, 1904.

Water resources of the Chambersburg and Mercersburg quadrangles, Pennsylvania, by G. W. Stose: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1904, pp. 156–158.

Water resources of the Curwensville, Patton, Ebensburg, and Barnesboro quadrangles, Pennsylvania, by F. G. Clapp: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1904, pp. 159–163.

Water resources of the Elders Ridge quadrangle, Pennsylvania, by R. W. Stone: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1904, pp. 164–165.

Water resources of the Waynesburg quadrangle, Pennsylvania, by R. W. Stone: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1904, pp. 166, 167.

Well records. (See reports of State Geological Survey of New Jersey.)

DELAWARE.

By N. H. Darton.

GEOLOGY.

This State lies almost entirely on the Coastal Plain, across which it extends diagonally to the Atlantic Ocean. The crystalline rocks emerge at the surface in the extreme northern portion of the State, but are deeply buried under the Coastal Plain deposits to the southeast. The general structure is shown in section 1, Pl. VII. The topography of the State is relatively simple, consisting of a general terrace plain averaging about 50 feet in altitude and a small area of higher rolling hills north and west of Wilmington. The geologic formations are as follows:

Formation.	Characteristics.	Age.
Columbia	Sands, loams, and gravel	Pleistocene.
Chesapeake	Sands, clays, infusorial earth, and marl.	Miocene.
Pamunkey	Brown sand and marl	Eocene.
Rancocas	Middle marl	Later Cretaceous.
Redbank	Sands and marl	Do.
Navesink	Lower marl	Do.
Matawan	Clay marl and sand	Do.
Raritan and Potomac	Clays and sands	Early Cretaceous.
Crystalline rocks	Granite, gneiss, gabbro, limestone, and quartzite.	

WATER HORIZONS.

As relatively few deep wells have been bored in Delaware, the water horizons have not been fully explored over a very wide area. The well at Middletown (see below) has obtained a fine supply of water from the Potomac formation, apparently from the basal beds, and it is probable that this water sheet extends from Wilmington past Middletown far southward. At Farnhurst it yields a moderate supply. The dip of the horizon to the south-southeast is about 30 feet to the mile, which carries it from the tide level at Wilmington to a depth of 165 feet at Farnhurst and 535 feet at Middletown. Water horizons above the lower beds of the Potomac formation and in the Matawan, Redbank, and Lower Marl, that occur in New Jersey, were not reported in the Middletown well, which probably indicates that these waters do not extend into Delaware. The principal Chesapeake horizons appear to be represented in Delaware, although the evidence in regard to their correlation is not conclusive. The basal Chesapeake water, so important in Maryland, has not been reached by the wells. The water from sands in the great diatom bed (the 525-foot horizon at Atlantic City) probably supplies the Dover and Mahon River wells with their large yields, while Milford and Lewes apparently obtain their waters from a stratum that lies just above the diatom bed. As the Kitts Hummock well draws from a bed about 125 feet above the horizon of Dover and Mahon waters, its water horizon can not be definitely correlated with any of those at Atlantic City. The Ocean City well in Maryland is a high Chesapeake horizon which probably extends into the southern edge of Delaware, but no wells have yet been sunk to it in that State.

WATER SUPPLIES.

DEEP WELLS.

There are only a few deep wells in the State, but they are all successful and nearly all furnish large supplies of water. The following is a list of some of the more important ones:

Partial list of deep wells in Delaware.

Locality.	Depth.	Diameter.	Capacity per minute.	Height to which water rises.	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Feet.*	
Dover	196	10	Flows 35 Pumps 218	+ 6	Water also at 157 feet.
Clayton	150	6	30	+20	No water at 85–150 feet.
Do	60	....	....	....	
Do	85	....	Moderate.	....	
Farnhurst	211	....	....	....	Water also at 40 and 60 feet; rock at 211 feet.
Kitts Hummock	110	1¼	Much.	− 2¼	
Lewes	400	6	15	To surface.	
Mahon River	206	....	Much.	....	
Middletown	535	10–8	330	−50	Fine quality of water; much water also at 475 and 530 feet.
Middletown	90	(?)	(?)	(?)	
Milford	160	4	60	− 2	
Do	150	4	60	+ 3	
Do	34	4	50	....	
Wilmington (Stoekle Brewery).	400	8	15–18	....	In granite.
Wilmington (H. & F. Brewery).	1,077	....	10	−25	In granite, 96–1,077 feet.
Wilmington (Hart & Bros.).	200	6	75	....	In granite, 36–200 feet.

WELL PROSPECTS.

From the evidence furnished by wells now yielding water supplies, it appears probable that the entire Coastal Plain area of Delaware is underlain by water. About Middletown and to the north the Potomac waters may be expected at depths which decrease at the rate of 30 feet per mile nearly to Wilmington, where the Potomac beds come to the surface. These waters may extend down the dip south of Middletown for many miles, but as no wells have been bored to them in that region no positive prediction can now be made as to the probability of obtaining water there. At Dover they should be expected at about 1,000 feet below the surface, if the southward dip continues at a uniform rate.

The Chesapeake waters begin a couple of miles north of Clayton and extend to the southern border of the State. The basal Chesapeake waters, which are important sources of supply in Maryland and in areas farther south, have not been tested by any wells in Delaware, but may be expected to extend over a wide area. The Clayton boring to 150 feet nearly reached this horizon, which probably lies about 450 feet below the surface at Dover. The Dover waters no doubt are widespread, for they are probably the same as those found at 234 feet at Federalsburg. The water horizon which appears to extend from Milford to Lewes probably also underlies all of eastern Sussex County, but it is not reported in any of the Maryland wells. In both Kent and Sussex counties there are almost certain prospects for Chesapeake waters at one horizon or another within 500 feet of the surface. Sections 1 and 2, Pl. VII, show the conditions so far as there are any data to present concerning them.

PRINCIPAL PUBLICATIONS.

(Well records.) See reports of State Geological Survey of New Jersey.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton: Bull. U. S. Geol. Survey No. 138, 1896, pp. 117-124.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, 1902, p. 21.

MARYLAND.

By N. H. Darton and M. L. Fuller.[a]

TOPOGRAPHY AND GEOLOGY.

The surface of Maryland may be divided into four topographic belts, determined by the composition and structure of the underlying rocks. Three of these, the Piedmont Plateau, the Appalachian Mountain, and Allegheny Plateau belts, are continuations of those developed in Pennsylvania and described in connection with that State. In addition to these there is in Maryland the great Coastal Plain belt, which stretches southeastward from a line extending from near Havre de Grace through Baltimore and Washington to Chesapeake Bay and the Atlantic coast. The materials of this belt are unconsolidated clays, sands, and gravels, mainly of Cretaceous and Tertiary age. When originally deposited the beds were very nearly horizontal, but they have been since tilted so that they now dip considerably to the southeast.

The Coastal Plain is moderately low and where not eroded by streams exhibits flat surfaces. Such flat areas, however, because of the extent to which erosion has taken place, are of no great extent.

The rocks of the Piedmont Plateau are mainly crystalline and include granites, diorites, and other igneous or metamorphic rocks, together with some schists, slates, and crystalline limestones. In altitude the belt is somewhat higher than the Coastal Plain area. Like the latter, it shows, in those portions untouched by streams, a nearly flat surface due, however, in this instance, to long-continued erosion at a period when the rocks stood near sea level, rather than to nearly level deposition, as in the Coastal Plain. The rocks, though deeply weathered, are harder than the Coastal Plain deposits and are less readily gullied by small streams. Moreover, they have been subjected to erosion for a much longer period than those of the Coastal Plain and more rounded forms have been developed.

Bordering the crystalline area and included partly within the area of Ordovician rocks to the west is a belt of Triassic sandstones and shales that ranges in width from 2 to 15 miles. The topography of this belt is similar to that of the Piedmont belt.

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[a] The following account of the water resources of Maryland has been prepared by M. L. Fuller, but the portions relating to the Coastal Plain have been compiled from the report of Mr. N. H. Darton on Artesian-well prospects in the Atlantic Coastal Plain region: Bull. U. S. Geol. Survey No. 138, 1896.

The Appalachian Mountain belt, as in Pennsylvania, consists of a series of strongly folded Cambrian, Ordovician, Silurian, and Devonian rocks, including a number of quartzites, sandstones, and limestones, lying mainly between Emmitsburg and Cumberland and striking northeast-southwest. Beyond Cumberland the rocks consist of moderately folded Devonian and Carboniferous strata, the harder beds of which give rise to ridges. These ridges are not, however, so strongly developed as those lying farther east, and in the areas between them plateaus similar to those of western Pennsylvania have been developed. As in the latter State the plateau in Maryland is deeply cut by the streams which drain it.

WATER SUPPLIES.

SPRINGS.

Springs are numerous throughout Maryland, but it is only in the limestones or coarse sandstones of the strongly folded Appalachian belt that they are commonly of any considerable size. In rocks other than limestones and sandstones the springs, though numerous, are small, but they nevertheless supply pure water for a large number of inhabitants in the more thinly settled districts.

In the crystalline rocks of the Piedmont Plateau springs are less common and are generally of small volume, but because of the demand for pure water for drinking purposes in the larger cities a number of such springs have been developed and their waters placed on the market. These are mainly in the vicinity of Washington and Baltimore.

The more porous beds of the Coastal Plain, where cut by ravines, give rise to numerous springs. These are commonly small and their water is frequently hard and is unsatisfactory for many purposes. Relatively little use is generally made of these springs, but a few of them that possess medicinal properties have been developed and their waters placed on the market.

The following is a list of springs reporting shipments in 1902:[a]

Blackiston Island Diuretic Mineral Spring, Blackiston Island, St. Mary County.
Bladensburg Spa, Bladensburg, Prince George County.
Carroll Springs, Forest Glen, Montgomery County.
Chattolanee Springs, Chattolanee, Baltimore County.
Elim or Willmead Spring, Oxenhill, Prince George County.
Mardela Mineral Spring, Mardela, Wicomico County.
Rock Hill Indian Spring, Rockville, Montgomery County.
Roland Park Artesian Well, Roland Park, Baltimore County.
Takoma Spring, Takoma Park, Montgomery County.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

Of these springs those in St. Mary, Prince George, and Wicomico counties are from Coastal Plain deposits. The remainder are probably from the crystalline rocks of the Piedmont Plateau. The aggregate production for 1902 is given as 488,228 gallons, with a value of $45,100.

STREAMS.

The small streams in the mountainous regions of Maryland are mainly spring-fed and contain in their upper courses very pure water. They soon become contaminated, however, by refuse from manufactories and villages situated along their courses, and, although frequently used as a source of water supply, they can not be regarded as a desirable source of water for domestic use. Moreover, they are often highly charged with silt.

The streams of the Piedmont and Coastal Plain belts are, because of the relative density of population of those areas, even more liable to pollution than those of the mountainous area and are seldom, if ever, desirable sources of supply.

WELLS.

Allegheny Plateau.—The Allegheny Plateau is developed only over a limited area in the extreme western part of the State. It is cut by the Potomac and Youghiogheny rivers and abounds in smaller streams. Springs are also common in this region. The surface waters are so abundant that the relatively small population depends largely on natural water supplies, very few wells being sunk except in the river bottoms, where good water is obtained at slight depth. Such wells as have been drilled, however, have generally procured considerable water from the shales and sandstones of the Carboniferous and Devonian. Several wells in the synclines or basins yield flowing water.

Appalachian Mountains.—There are a few wells in the river bottoms and there is an occasional shallow rock well in the limestone or shale valleys in the Appalachian Mountain belt, but deep wells are lacking, springs constituting almost the only source of natural supply. Cisterns are sometimes used.

Piedmont Plateau.—The surface of the Piedmont Plateau is here, as elsewhere, made up of more or less deeply weathered and jointed crystalline rocks. These contain considerable water in the aggregate, many shallow wells deriving their supplies from their weathered upper portions, while other wells obtain water from joint fissures at greater depths. The occurrence or nonoccurrence of water at a given point can seldom be predicted, however, because of the great variability of the governing factors. The largest supplies are obtained from these rocks near the cities of Baltimore and Washington, each of which is discussed separately.

Coastal Plain.—The Coastal Plain region in eastern Maryland presents the usual general structural relations, but certain local features are conspicuous. The Raritan formation merges into the underlying Potomac formation; the upper marl of the marine Cretaceous thins and changes to more clayey beds, and only the middle and lower members continue southward, where they have been designated the Severn formation; the Pamunkey greensand marl comes in, and the plateau areas capped by the Lafayette formation become characteristic features. The formations are as follows:

Coastal Plain formations in Maryland.

Formation.	Characteristics.	Age.
Columbia	Loams, sands, and gravels on terraces	Quaternary.
Lafayette	Gravel, sands, and loams	Pliocene?
Chesapeake	Sands, clays, infusorial earth, and marl.	Miocene.
Pamunkey	Glauconitic marls and sands	Eocene.
Severn	Black argillaceous, carbonaceous sands.	Cretaceous.
Magothy	White sands and brown sandstones	Cretaceous.
Potomac	Clay, sands, and gravels	Early Cretaceous.

In the following table is given a list of the more important localities obtaining deep or artesian waters. Baltimore wells are not given, but are considered on a subsequent page:

Statistics of deep-well localities in Maryland.

Locality.	Range of depth.		Range of capacity per minute.		Geologic horizon of water.
	From—	To—	From—	To—	
	Feet.	*Feet.*	*Gallons.*	*Gallons.*	
Agricultural College		150		5	Basal Potomac.
Annapolis		201			Magothy.
Bay Ridge		470		20	Mid-Potomac.
Bowie		384	0		In Potomac.
Bushwood		287			Low in Pamunkey.
Cambridge, 6 wells		370	160	each, 250	Basal Chesapeake.
Chapel Point		237			Basal Pamunkey.
Claiborne	100	440		Many	Magothy, in Pamunkey.
Cornfield Harbor		360			Basal Chesapeake.
On farm	240	370			Chesapeake, Basal Chesapeake.
Crisfield	1,018	1,090	40	200	Magothy, Potomac.
Denton		359		30	
Easton, 6 wells	102	600	0	each, 75	Low in Chesapeake, Into Pamunkey, Low in Severn?
Federalsburg		234		20	In Chesapeake.
Indian Head		463½		11½	In Potomac.
Laurel		148½		10	Basal Potomac.
Le Compt's store		358		4	Basal Chesapeake.
Leonardtown		300		2	Do.
Marlboro		222		25	Magothy?

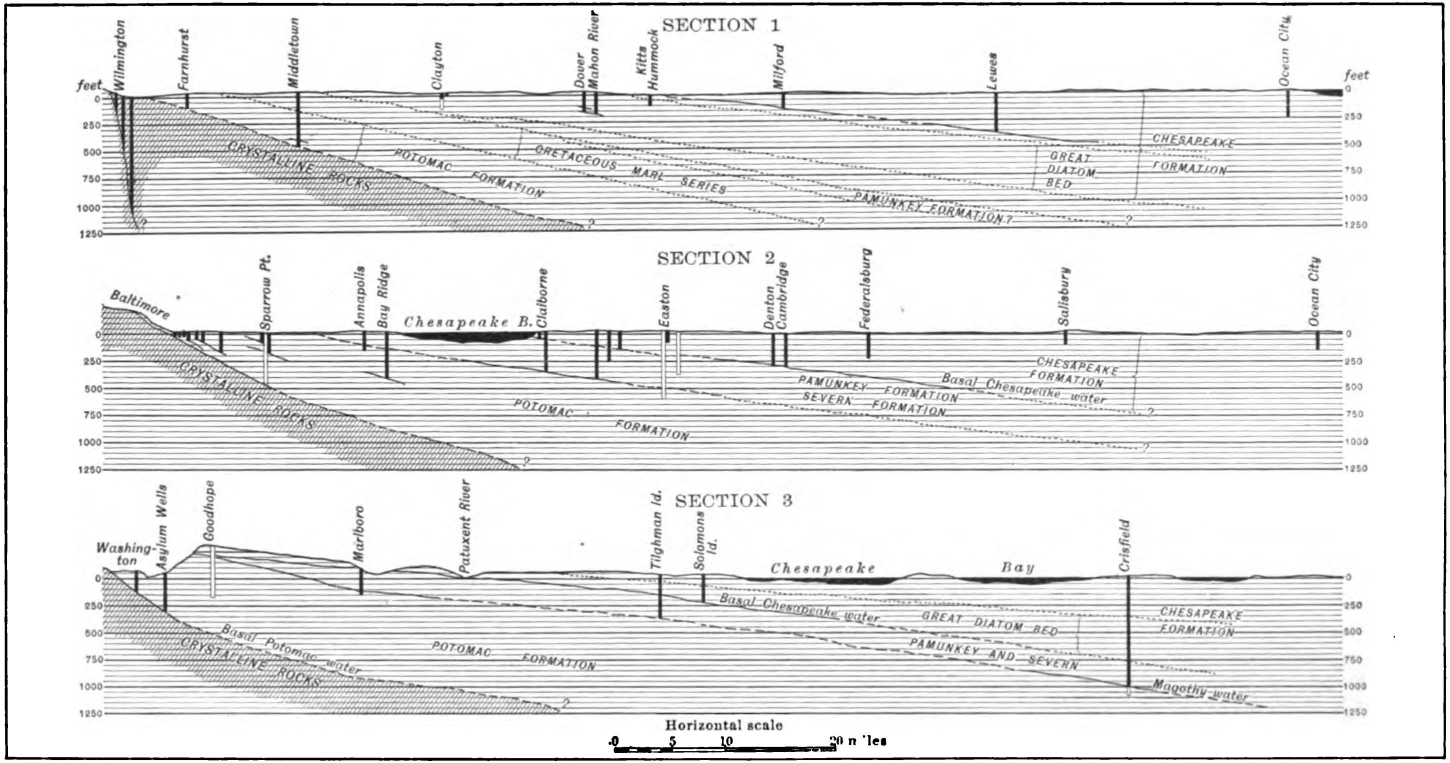
Statistics of deep-well localities in Maryland—Continued.

Locality.	Range of depth.		Range of capacity per minute.		Geologic horizon of water.
	From—	To—	From—	To—	
	Feet.	*Feet.*	*Gallons.*	*Gallons.*	
Miles River Neck ("Anchorage")		265		15	In Pamunkey.
Miles River Neck (Long Point)		195		5	Basal Chesapeake.
Nanjemoy (Landing)		175		1	Basal Pamunkey.
Oakley		305		7	Low in Pamunkey.
Ocean City		256		130	High in Chesapeake.
Patuxent River, at B. & P. R. R.		152		20	Basal Potomac?
Piney Point		270		5 (?)	Basal Chesapeake.
Rousby on Patuxent		240		Many.	Do.
Rock Point, Charles County.		254		3	Do.
St. George Island, 25 wells.		270		each, 2-5	Do.
St. Inigoes, 10 wells, "Jutland."		365		1	Do.
Salisbury		101		350	High in Chesapeake.
Solomons Island, 2 wells.	252	258	10	each, 150	Basal Chesapeake.
Tilghman Island		400		Many.	Magothy?
Tunis Mills, on Miles River Neck.		430	Flows, 6	Pumps, 100	Do.

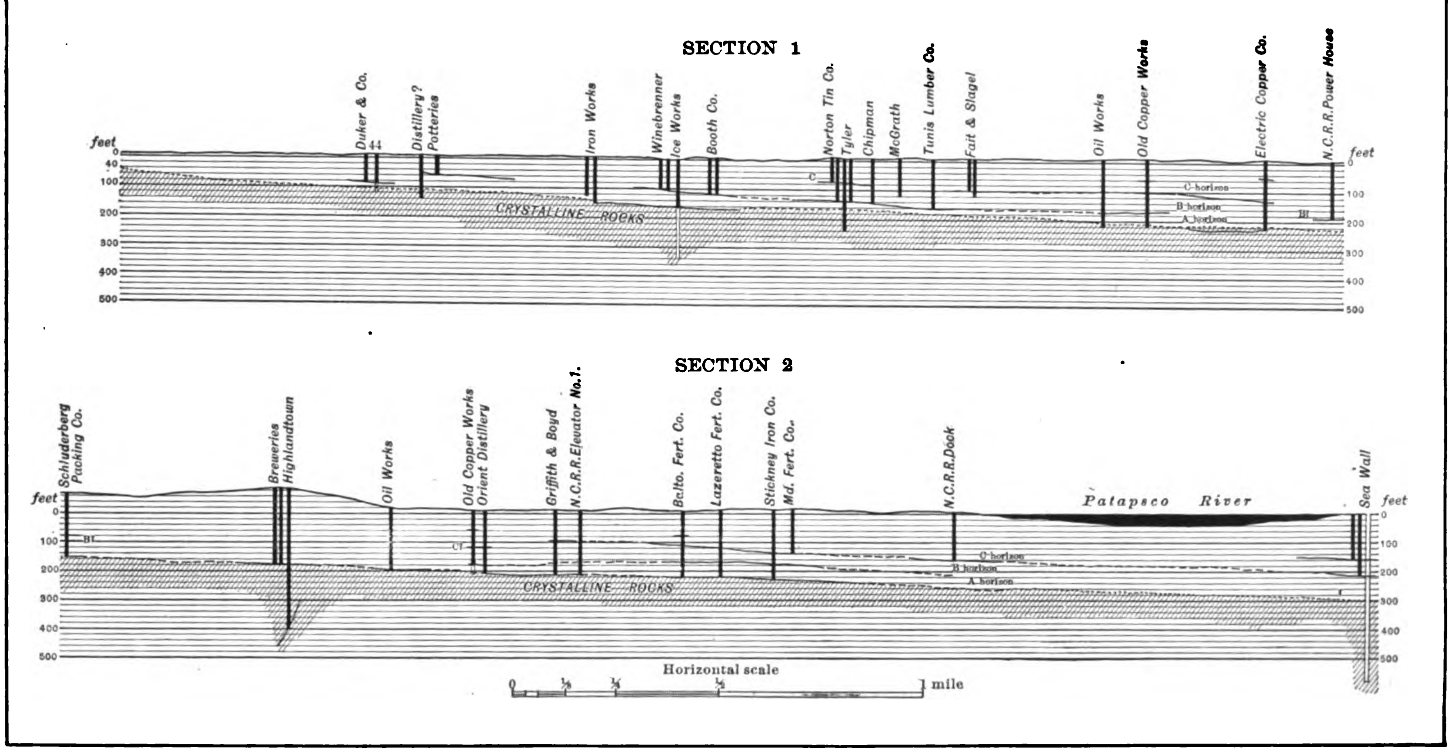
WATER HORIZONS.

It is now known that the greater part of the entire Coastal Plain region of Maryland is underlain by several horizons of water-bearing beds. The distribution of wells and water horizons is represented in the cross sections of Pl. VII.

The gravels and sands of the basal beds of the Potomac formation that lie on or near the floor of crystalline rocks are the principal sources of water for wells sunk in the western portion of the Coastal Plain. How far southeastward this water horizon may extend has not been determined, but probably it will yield water in many areas nearly to the Atlantic coast. To the east and south the dip of the Potomac horizon carries it to a great depth, but there are several strata of water in higher beds in the Potomac, and in other formations at more moderate depths. The easternmost successful wells which have reached the base of the Potomac formation are those in the southeastern portion of the Baltimore region, in the District of Columbia, and at Middletown, in Delaware, all of which are only a few miles from the outcrop of the formation, so that the eastern extension of the basal Potomac waters is not known over a very great breadth of territory. The failure of a well at Sparrow Point to find water in the basal beds indicates also that the sheet of water is not general at this horizon.



SECTIONS IN MARYLAND AND DELAWARE.



SECTIONS IN BALTIMORE REGION.

The water horizons lying at various distances above the basal beds. but within the Potomac formation, have been extensively explored in the vicinity of Washington and Baltimore, where they appear to be widespread and satisfactorily productive. They have also been reached in a Marlboro well at a depth of 216 feet, and in a well at Indian Head at 459 feet. A well at Bowie found no satisfactory supply of water to within about 200 feet of the base of the formation, nor was a well on Spesutie Island a success, though it appears to have penetrated the Potomac beds to a considerable distance. The sands of the Magothy formation, which underlie the Potomac, appear to be water bearers over a wide area on the Eastern Shore of Maryland, as is probably indicated by wells at Claiborne, Tilghman Island, and Crisfield, and possibly also at Tunis Mills. They underlie the central area of the Western Shore southeast of a line from Bowie to the mouth of the Patapsco River, but do not appear to yield water in Marlboro, Annapolis, and Bay Ridge wells. A boring to 600 feet at Easton, unfortunately, probably did not thoroughly test this horizon, otherwise we might have had some important evidence for that portion of the Eastern Shore region. A 265-foot well on Miles River Neck appears to draw its water from a horizon in the Pamunkey formation, but this well is the only indication of a water horizon in these formations in the Eastern Shore region. In wells at Colonial Beach, Va., and at Nanjemoy, Chapel Point, and Rock Point, in Charles County, the basal Pamunkey beds yield water which probably underlies much of southern Maryland southeast of a line from Herring Bay to Liverpool Point.

The basal Chesapeake water horizon, which is well explored in Virginia, yields water over a wide area in the southern counties of the Western Shore at depths from 200 to 300 feet, as in wells at Solomons Island, Leonardtown, Piney Point, St. Inigoes, and St. Georges Island. At Cornfield Harbor it is 365 feet. This horizon also furnishes large water supplies at Denton, Cambridge, and Le Compt's store, and possibly in a well 195 feet deep on Miles River Neck, on the Eastern Shore. It was not found at Crisfield, nor in a deeper boring at Easton, although the associated sandstone bed was reported at Easton. The higher Chesapeake horizons are important in New Jersey and Delaware, and, although not extensively tested in southern Maryland, they probably underlie a considerable area of the Eastern Shore. At Easton the large water supply in wells 100 feet deep is derived from a horizon in the Chesapeake formation about 150 feet above its base, and the Federalsburg water, which lies at a depth of 234 feet, is either at the same horizon or at one not a great distance above. The small showing of water at 160 feet at Leonardtown appears to be a local occurrence, for it was not reported in other wells to the east. Unsatisfactory water was obtained at Salisbury from a much higher horizon, and the flow of fine water at Ocean City is from a still higher horizon of the Chesapeake formation. In the wells at and near Cambridge and at Crisfield no waters were reported above the basal Chesapeake beds; so we must conclude that the higher waters do not extend in that direction.

BALTIMORE DISTRICT.

GEOLOGY.

Baltimore lies in the zone in which the crystalline rocks emerge from beneath the Coastal Plain deposits. Although in greater part it is built on the Potomac formation, the depressions of Jones and Gwynns falls are excavated to the crystalline rocks, and these rocks rise rapidly to constitute the surface in the region north and west of the city. The Potomac formation consists of its usual materials, in which predominate clays of various colors and fine sands. Toward its base there are beds of coarse sands and gravels, and at the base an almost general occurrence of these materials, lying on a floor of crystalline rocks. Some features and relations of these basal beds are shown in Pl. VIII. The coarse materials contain widely extended sheets of water, which have been tapped by many well borings of moderate depth. The rock floor slopes rather steeply eastward, at a rate averaging about 65 feet per mile, but the rate appears to increase locally to 100 feet along by the Basin. The basal gravels pass beneath tide water along a line extending from the lower Baltimore and Ohio Railroad bridge over Gwynns Falls to the Fayette Street Bridge over Jones Falls, and thence due east-northeastward. The principal water supplies are found south of this line, for in the area to the north the waters are free to flow laterally into the depressions of Jones and Gwynns falls. The basal gravels emerge in the northern portion of the city, although in some areas they are overlain by a thin cap of gravels and loams of earlier (Columbia) age. They cap the Druid Hill Park region, the ridges for some distance out Charles street, Roland avenue, and York, Harford, and Belair roads, and the high region about Catonsville. In these outlying extensions the basal gravels constitute a capping on the crystalline rocks which averages from 10 to 30 feet in thickness. The principal structural relations are shown in the sections on Pl. VIII. On Patapsco River Neck the Potomac formation rapidly thickens as the crystalline rock floor descends to the east, and at Sparrow Point its thickness was found to be 500 feet. The higher ridge which extends along the northern portion of this neck is capped by a thin mantle of earlier Columbia gravels and loams, and the lower terraces consist of later Columbia loams and sands, with some gravel in the lower beds. These formations, however, are not involved in the question of the deeper water supply.

The crystalline rocks present considerable variety of materials, but gneiss and granite, or "gray stone," and "nigger head," or gabbro, are the most conspicuous varieties. They are all considerably fissured and often deeply decomposed along fissures or veins of moderate width and extent. The fissures or veins are usually nearly vertical and extend from northeast to southwest. They are water-bearers in greater or less measure, but their distribution and extent have not been determined, except in the case of the one along Belair road, which has been tested for a short distance.

WATER HORIZONS AND WELL PROSPECTS.

Canton.—The wells in Canton indicate the presence of several widely extended sheets of water-bearing gravels, the upper layers of which are interbedded between sheets of clay and fine sand, the lower bed lying on the floor of crystalline rocks. The dip is to the southeast at rate of about 60 feet per mile. In Pl. VIII the first section lies along Clinton street from Highlandtown to Thirteenth avenue and across Patapsco River to Seawall. The three principal water horizons are lettered A, B, and C. They occur from the bed rock up at intervals that average 40 feet.

There are several wells north of Canton, at Highlandtown, which yield large water supplies. At the National Brewery there are two wells to 240 and 450 feet, and at Gunther's brewery two wells to 207 and 208 feet. The waters at 207 and 240 feet are probably in basal Potomac beds, or at Horizon A, as shown in section 1, Pl. VIII. At Schluderberg's packing house a well yields water at 135, 160, and 210 feet, and the 160-foot or third horizon was tested to 150 gallons a minute. The basal beds of the Potomac formation probably carry the water found at 210 feet.

East Baltimore, from Canton to the Basin.—There are only a few wells in the vicinity of Jones Falls, and they are not very successful, but from the foot of Patuxent street to Ann street there are 25 wells, nearly all of which are large producers of excellent water. The average depth is between 80 and 120 feet, and the principal water horizon is B of the Canton region, but A and C also are found. Section 2 of Pl. VIII illustrates the principal relations.

The large water supply found in the basal Potomac beds, Horizon A, appears to extend to the north and west, but it was not reported half a mile southeast. The greater number of the wells in this district find abundance of water in Horizon B, about 40 feet above the basal beds.

What appear to be the sea horizons of the Canton region yield water in places.

In the region immediately adjoining Jones Falls and for some distance to the west on the north side of the Basin deep wells do not yield satisfactory water supplies on account of the proximity of the basal and lower Potomac beds to the surface. Several wells have penetrated the crystalline rocks and found a fair supply of satisfactory water.

Region between the Basin and the harbor and Middle Branch.—There are several wells along the north side of Locust Point from the Basin to Fort McHenry, which yield satisfactory water supplies from the Potomac horizons.

Probably Horizons B and C underlie all of the Locust Point region, and Horizon A, in the basal beds, may possibly occur at some localities southeast of the Federal Hill region.

On the Ferry Bar peninsula there are a few widely scattered wells, which, however, indicate that the favorable conditions in Canton and on Locust Point continue to the west, and that abundant waters may be obtained in Horizons C, B, and A. The shallower waters are unsatisfactory in quality, but the deeper waters give no scale in boilers and occur in large amounts.

Between the Basin and Ridgely Cove a number of attempts have been made to obtain water from the crystalline rocks, with varying degrees of success.

Region from Brooklyn to Curtis Bay.—The successful group of wells at Seawall and at South Baltimore (Curtis Bay) indicates a wide and general extension of the Potomac waters under the Curtis Bay-Patapsco River peninsula. The Seawall water at 217 feet appears to represent Horizon C. The 562-foot boring at Seawall no doubt demonstrates the absence of water in the basal Potomac, or Horizon A, in that vicinity, and also in the underlying crystalline rocks.

Region southeast of Canton to Sparrow Point.—The wells of St. Helena, Dundalk, and Sparrow Point are included under this heading. Their relations are shown in section 2, Pl. VIII. The wells at St. Helena are probably in Horizon C, and the water at 230 feet at Dundalk is thought to be in Horizon B, which probably would have been found at 200 feet at St. Helena. The 120-foot water at Dundalk is possibly the deepest water of Sparrow Point.

The Sparrow Point wells are a most satisfactory group of water producers. Their principal supply is obtained at a depth of 125 feet from a horizon high in the Potomac formation, for a well sunk to a depth of 495 feet just reached the granite bed rock. In this deep well no water was found below 210 feet, which indicates that the lower water horizons do not extend far eastward in this region. The one well which draws 100 gallons a minute from a depth of 210 feet obtains its supply from a horizon which can not be definitely correlated with those of wells farther northwest.

Northeast Baltimore.—Several breweries in this section of the city have deep wells, some of which yield satisfactory water supplies. They all penetrate the crystalline rocks and obtain water from fissures or decomposed portions of these rocks in fair supply, but when wells were sunk to 315 and 400 feet at the Bauernschmidt brewery, a block southwest, the supply at once diminished to a very small amount. The well at the Brehm brewery, which is some distance east of the Belair road and several squares beyond North avenue, was sunk in the rock to a depth of 1,300 feet without finding water, but it is considerably east of the line of the other wells.

The Darley Park Brewery well, on the Harford road, three squares north of North avenue, is west of the Belair-Gay street line of wells. The waters from these wells differ considerably in character, but in greater part they are satisfactory for boilers and drinking, although in some cases the water is too ferruginous for general use.

Western part of Baltimore.—Except the well at the Lipp Soap Works, at Hollins street and Calverton Road, no specific data for borings in the western part of Baltimore are at hand. The soap works wells are in crystalline rocks and reach a vein or fissure which yields a good supply of water of excellent quality.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 51-53.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton: Bull. U. S. Geol. Survey No. 138, pp. 124-155.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, p. 50.

Water resources of the Accident and Grantsville quadrangles, Maryland, by G. C. Martin: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1905, pp. 168-170.

Water resources of the Frostburg and Flintstone quadrangles, Maryland and West Virginia, by G. C. Martin: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1905, pp. 171-173.

Description of the Fredericksburg quadrangle, Maryland and Virginia, by N. H. Darton: Geol. Atlas U. S., folio 13, U. S. Geol. Survey.

Description of the Nomini quadrangle, Maryland and Virginia, by N. H. Darton: Geol. Atlas U. S., folio 23, U. S. Geol. Survey.

Description of the Washington quadrangle, Maryland, District of Columbia, and Virginia, by N. H. Darton and A. Keith: Geol. Atlas U. S., folio 70, U. S. Geol. Survey.

DISTRICT OF COLUMBIA.

By N. H. **Darton** and M. L. **Fuller.**

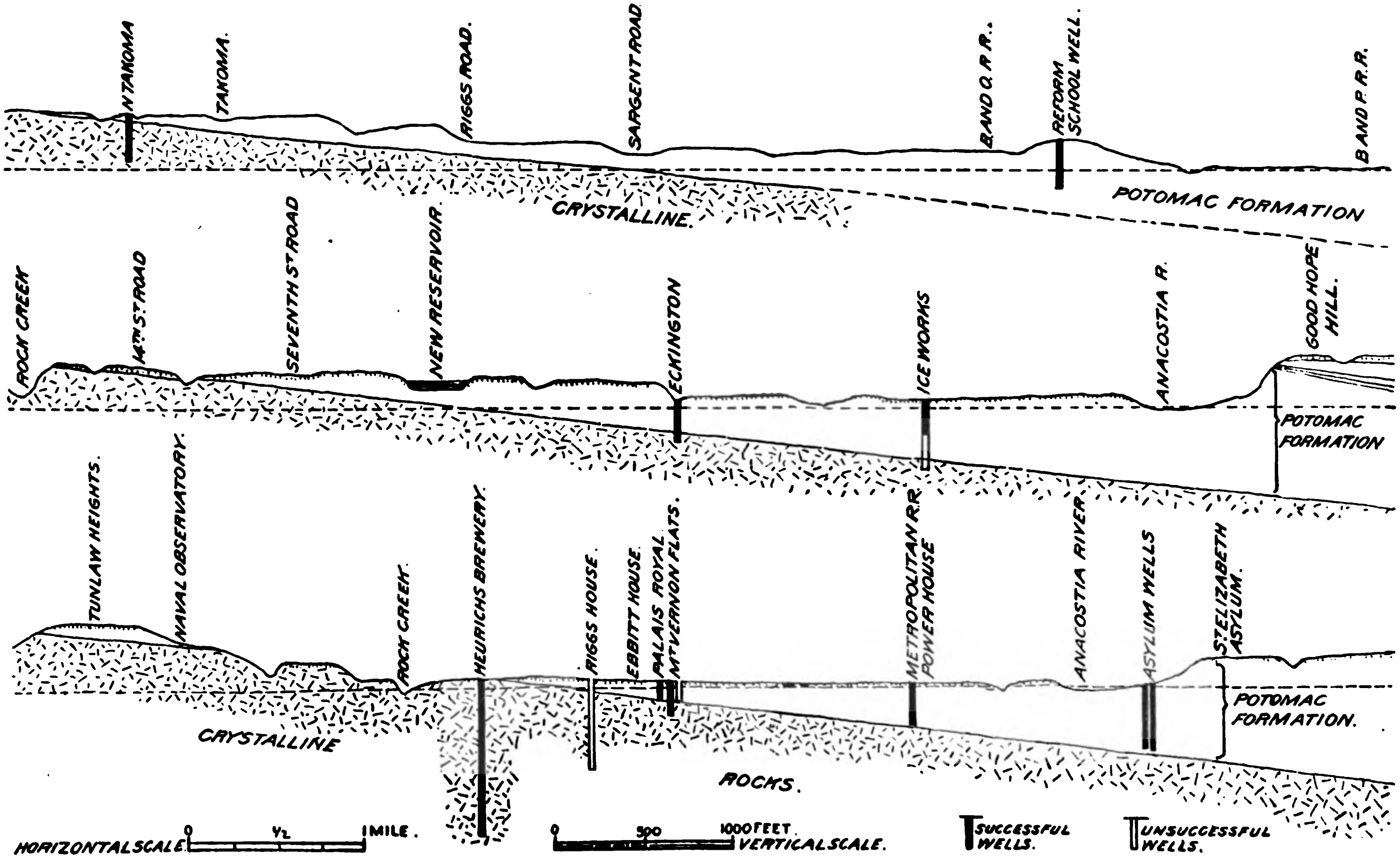
GEOLOGY.

The District of Columbia extends across the zone in which the crystalline rocks emerge from beneath the Coastal Plain deposits and rise into the Piedmont Plateau to the west. The contact line crosses the Potomac River at Washington, passes through the western portion of the city, and extends northward along the east side of Rock Creek Valley. The formation that lies on the crystalline rocks is the Potomac, which consists mainly of water-bearing sands and gravels below and of clay and fine sands above. The Potomac formation has in all a thickness of about 700 feet, and outcrops in a belt from 7 to 8 miles wide, which extends eastward high up the slopes on the east side of Anacostia River. In these slopes it is surmounted by younger formations, consisting of a succession of the thin western edges of the dark sandy clays of the Severn formation, the impure marl of the Pamunkey, the gray clays of the Chesapeake, and the gravels of the Lafayette. Washington is situated on a series of broad, low terraces cut in Potomac sands and clays and across the edge of this formation into the crystalline rocks.

This series of terraces and its extension along all the lower land of the District is capped by from 20 to 35 feet of gravelly sands and loams of the Columbia formation. In the three sections in Pl. IX a fairly clear representation is given of the structure of the Washington region. It is in Good Hope Hill that the Potomac formation passes under the Severn, Pamunkey, Chesapeake, and Lafayette formations, as shown in section 2, but there are also small outlying areas of the Chesapeake and Lafayette formations on the high lands of Soldiers' Home Park and the ridge which extends to Tenley.

WATER HORIZONS AND PROSPECTS.

Waters of the crystalline rocks.—Under this head are included the waters of the consolidated rocks of the Piedmont Plateau portion of the District. These rocks comprise granite-gneiss, biotite-granite, diorite, etc., and are generally deeply weathered and cut by numerous



SECTIONS IN DISTRICT OF COLUMBIA.

joints. The disintegrated nature of the outcrops is favorable to the absorption of considerable quantities of water and the broken-up rock acts as a filter. In general, the area of the consolidated rocks is relatively thinly settled and little demand is made on it for water supplies, except by shallow wells. The few deep wells that have been put down, however, show that moderate amounts of good water can frequently be obtained, although, because of variations in the density of the rock and in the number of joint fissures, the conditions are far from constant.

The surface of the consolidated rocks slopes southeastward from Rock Creek, where it is exposed at an elevation of 200 feet, at an average rate of 110 feet to the mile. It lies at a depth of about 100 feet below tide level in the center of the District and of about 600 feet at the southeastern boundary. The crystalline rocks are not depended upon as a source of water east of Rock Creek because of the greater quantities that are found in the sedimentary beds that overlie them in this region.

Waters of the sedimentary rocks.—All of the sedimentary formations carry more or less water, but, except in the case of the Potomac, the flows are small and the quality is not the best. This is especially true in the isolated areas capping the hills of crystalline rocks, even the Potomac frequently failing in such localities.

The Potomac is the principal water-bearing formation of the area; it constitutes the surface material over most of the Coastal Plain portion of the District, having a catchment area from 6 to 8 miles in width. Its base rests on the crystalline rocks, dipping southeastward with the latter. Its total thickness, as pointed out, is about 700 feet.

The deeper-seated underground waters have been tapped by a sufficiently large number of wells in the District to demonstrate the almost general extension of water-bearing beds in the basal and lower bed of the Potomac formation, and there is often a fair prospect for finding water in the crystalline rocks. The wells that did not find a satisfactory water supply in the basal Potomac beds are at the Ice Works at a depth of 360 feet, and at the Mount Vernon Apartment House at 133 feet. On the other hand, the St. Elizabeth, Metropolitan Railroad power house, Palais Royal, Eckington, Washington Brewery, and National Capitol Brewery wells obtain large supplies from that horizon. In surface outcrops the basal Potomac beds are usually coarse sands and gravels, which are filled with water, but there are some local areas in which there is a clay matrix, or even pure clay, extending down to the crystalline floor. This was found to be the case at the Mount Vernon Apartment House, while at the Palais Royal, three squares southwest, the basal beds were coarse sands and gravels containing much water. In the 380-foot well at the Ice Works coarse basal beds were found, but they contain no large supply of water. This leads to the conclusion that the waters are in part choked off toward the north by a local area of clayey beds which does not influence the wells at the breweries near by.

Besides the basal sands and gravels of the Potomac there are beds of sand or gravel at several other horizons, especially near the top. Although of somewhat uncertain persistence and character they are so numerous that good flows can generally be obtained at or even considerably above sea level. As these beds occur in the District only near its southeastern border they are not here important sources of water, the underground water supply of the District being derived, as stated, mainly from the lower beds.

In general the dip of the Potomac formation corresponds roughly with the slope of the surface of the underlying crystalline rocks, decreasing from an elevation of 200 feet above sea level just east of the Zoological Park to sea level in the vicinity of New Hampshire avenue, 200 feet below sea level at the Capitol, 300 feet at Lincoln Park, 400 feet near Anacostia River, and 600 feet at the District line; hence there is a constant increase southeastward in the depths to which wells must be sunk to the water-bearing beds.

In general it may be said that the prospects are good for obtaining supplies from the basal beds of the Potomac, while there is always an additional chance of finding water in the overlying beds, as at the ice works. Notwithstanding the density of the population of almost the entire catchment area in the District, the organic impurities of the water are largely oxidized and removed in consequence of the natural filtration through the soil and sands, so that the supply from deep wells is usually satisfactory as regards purity.

Mineral springs.—Springs are fairly numerous in the District of Columbia, but in general consist only of small seeps from the disintegrated crystalline rocks or from the sandy portions of the Coastal Plain formations. A number have been developed, however, and water to the amount of 212,100 gallons, with a value of $12,105, was placed on the market in 1902.[a] These are listed below:

Columbia Natural Lithia Spring, Washington.
Crystal Spring, Washington.
Gitchie Crystal Spring, Benning.
Laurelwood Spring, Mount Pleasant.

PRINCIPAL PUBLICATIONS.

Artesian-well prospects of the Atlantic Coastal Plain region, by N. H. Darton: Bull. U. S. Geol. Survey No. 138, pp. 155-161.

Description of the Washington, D. C., quadrangles, by N. H. Darton and A. Keith: Geol. Atlas of U. S., folio 70, U. S. Geol. Survey.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

VIRGINIA.

By N. H. Darton and M. L. Fuller.

PHYSIOGRAPHIC DIVISIONS.

There are four well-defined geologic and topographic belts in Virginia: (1) The Coastal Plain, (2) the Piedmont Plateau, (3) the Appalachian Mountain belt, and (4) the Cumberland Plateau. The first three are prolongations of the belts of the same name in Maryland, with which they agree in character. The fourth corresponds in a general way with the Allegheny Plateau of Pennsylvania and Maryland, although its surface was not produced at the same geologic period.

GEOLOGY AND WATER HORIZONS.

COASTAL PLAIN.

GEOLOGY.

The Coastal Plain region of Virginia lies east of a line which passes through Alexandria, Fredericksburg, Bothwell, Richmond, Petersburg, and Emporia, comprising an area of about 9,500 square miles. This district is traversed from northwest to southeast by a series of great rivers, which divide it into a succession of long ridges. These ridges are remnants of a plateau surface which slopes from an altitude of from 300 to 200 feet at the western margin of the Coastal Plain to an altitude of about 100 feet on its eastern margin. The larger rivers are tidal estuaries that occupy low valleys and meander through wide terrace plains. Chesapeake Bay is widely bordered by these interstream terraces, while the Eastern Shore of Virginia, which lies east of the bay, is a low plain, as is also the wide area which lies between Dismal Swamp and the Atlantic Ocean.

The geologic structure of the region is in general similar to that of eastern Maryland, but there are certain differences in the stratigraphy. In the outcrop zone the Potomac formation becomes predominantly sandy and the Severn and Magothy sands are absent, so that the Pamunkey marls lie directly on the surface of the Potomac beds. Far eastward, under the bay and the Eastern Shore, there is probably presented the same sequence that is found in Maryland. The Chesapeake formation extends farther westward in southern Virginia and often overlaps on the crystalline rocks. In the sections, Pl. X, there are shown the general structural relations in Virginia so far as they are known. The Coastal Plain formations that outcrop in the State are as follows:

Coastal Plain formations in Virginia.

Formation.	Characteristics.	Age.
Columbia	Loams, sands, and gravels in terraces	Pleistocene.
Lafayette	Orange sands, loams, and gravels	Pliocene?
Chesapeake	Clays, sands, infusorial earth, and marl.	Miocene.
Pamunkey	Glauconitic marls and sands	Eocene.
Potomac	Sands, sandstone, and clays	Early Cretaceous.

WATER HORIZONS.

The greater part, if not all, of the Coastal Plain region of Virginia is underlain by water-bearing strata, of which, to the east, there are several horizons. The failures to obtain the higher water in some of the wells near the bay indicate that in this area at least there are no good water supplies in the higher horizons, but the waters of the lower horizons have not yet been fully developed. The success of the new well at Fort Monroe definitely proves the existence of one of these. The failure of a single well, as at North End Point, does not always disprove the existence of a water horizon, for in many instances water has been passed unnoticed, or willfully, by well borers.

The principal water horizons in eastern Virginia are the Chesapeake, the Pamunkey, and the Potomac.

Potomac.—There is more or less water in all of the coarser sand beds of the Potomac formation, but the principal supplies may be expected from the sands and gravels of the basal members lying on the basement floor of crystalline rocks. This horizon has yielded much water about Washington, Alexandria, Quantico, and Walkerton. It is probably a strong water-bearer throughout a wide extent. Its general relations are shown in Pl. X.

Water occurs at various horizons in the Potomac formation above the basal beds in sands interbedded among the clays. This water is an important source of supply in the District of Columbia and at Barrow, near Quantico, but elsewhere it has not been fully tested.

Pamunkey.—The coarse gravel and sand at the base of this formation appears to be a water-bearer throughout a considerable area, furnishing supplies at Naylors Wharf, Chapel Point, Md., Colonial Beach, Lester Manor, and Whitehouse.

The meager supply of water in the Clay Bank well and the failure of the deeper borings at Williamsburg and Gloucester probably indicate the eastern limits of the horizon as a water-bearer. It may extend under all of the region south of the James River, although none of the wells appear to have been bored sufficiently deep to reach it. It is to be expected that toward the east the materials at this horizon finally become too fine-grained to carry water, and the eastern limit of conditions favorable for water bearing appears to be at Clay Bank, on York River.

Water also occurs in sands in the Pamunkey formation about 90 feet above its base, as is indicated by the water at 160 feet at Colonial Beach, and at 275 to 325 feet at Naylors Wharf; but as it has not been further explored by other wells, its extent can not be discussed.

Chesapeake.—Lying between the clays, marls, and fine sands of the Chesapeake formation and the top of the Pamunkey formation there is a series of sands and gravels which may be regarded as the basal bed of the Chesapeake formation. Toward the east this series contains thin interstratified rock strata, which do not appear in the surface outcrops. In this series, and in another similar one not far above, there is a large volume of water, at a horizon or horizons which appear to be of wide extent in eastern Virginia. These waters have been explored by many wells and have been found to underlie a belt of country about 20 miles wide lying east of a nearly straight line extending from Mathias Point, on the Potomac River, to Emporia, on the Atlantic Coast Line Railroad.

Basal Chesapeake waters were apparently absent in the North End Point, Fort Monroe, Dendron, Clay Bank, and Gloucester wells. The wells at Crisfield, Md., found no appreciable supply of water in the basal Chesapeake beds.

There are several higher water horizons in the Chesapeake formation, and it is believed that certain wells at Franklin, Zuni, Bowlers Wharf, and Mount Carmel draw water from Chesapeake beds that lie about 100 feet above the base of the formation.

WELLS.

The occurrence of the underground waters is well brought out by the list of some of the more important wells of the Coastal Plain presented in the following table. It will be noted that the supply per minute and the bed from which the water is obtained is indicated in each case.

Partial list of deep wells.

Location.	Depth.	Size.	Capacity per minute.	Height to which water rises. a	Horizon.	Remarks.
	Feet.	*In.*	*Gallons.*	*Feet.*		
Alexandria Brewery	430	8	90	....	Basal Potomac	Soft water.
Alexandria Ice Works.	401	8	20	−12	....	Poor water at 300 feet.
Arringdale, 2 wells	75	......	Flows 10	+10	....	Slightly alkaline water.
Ashland	79	1½	Many.	−4½	Granite?	
Do	100	4	Many.	....	Granite	
Barrow	195	......	Many.	....	In Potomac	No water below 143 feet.
Bellevue, 2 wells	212	1½	Flows 15 to 20	+4 to +6	Basal Chesapeake	
Bothwell	300	6	20	−7	Newark	
Bowlers Wharf	143	4	7	Flows.	Chesapeake	Soft water.
Carters Creek	330	......	....	+12	.....do	
Clay Bank	538	1½	Flows 2	+4	Basal Pamunkey?	
Clifton, 2 wells	175	1½	Flows 10 to 12.	+4 to +6	.....do	
Coan, 8 wells	270	1½	Flows 2½	+12	Basal Chesapeake	Water also at 240 feet.
Coan, 1 well	315	4	15	+12	.....do	
Coles Point	220	1½	3	+12	.....do	
Colonial Beach, 5 wells.	250	1½	5	+8 to +15	Basal Pamunkey	Water also at 160 feet.
Courtland, 30 wells	160	......	30	....	Chesapeake?	
Cowart	288	2	Flows 2	+6	Basal Chesapeake	
Ditchley	620	1½	Flows 2	+4 to +6	....	
Dendron	386	6	None.	....	....	
Dudleys Ferry, 4 wells.	175	1½	Flows 10	4 to 6	Basal Chesapeake	
Dymer Creek	507	3	Flows 7	....	Basal Pamunkey	Water also at 240 and 464 feet.
Fairport	393½	1½	Flows 2	....	Basal Chesapeake	Soft, good water.
Fort Monroe	907	......	None.	....	Potomac?	
Fort Monroe, Chamberlin Hotel.	945	......	Flows 50	+10	.....do	Slightly saline water.
Franklin, 16 wells	130	......	Many.	Flow.	Chesapeake	
Gabels Mill	226	1½	Flows 20	+10	Basal Chesapeake	
Gloucester Court House.	600	......	None.	....	Pamunkey?	Stopped at rock stratum.
Homewood, 5 wells.	317	1½	Flows 30	....	Basal Chesapeake	Fine water 54°. Sulphurous water at 270 feet.
	112	1	Fair supply.	+2	Chesapeake	Ferruginous water.
Jamestown	248	3	Flows 2½	+35	Basal Chesapeake	Fine water 68°.
King and Queen	200	2	Flows 1	....	Basal Pamunkey?	
Kinsale	235	1½	5	+15	Basal Chesapeake	
Lancaster	250	......	Flows 12	....	.....do	
Do	285?	......	....	....	....	
Lester Manor, 3 wells	200	1½	Flows 12	+8 to +12	Basal Pamunkey?	
Lewisetta	317½	......	....	....	Basal Chesapeake	
Little Plymouth	168	2	Flows 2	....	.....do	
Monaskon	255	......	....	....	.....do	
Monatico Creek	250	1½	Flows 2	+	.....do	
Mount Carmel Church.	190	......	Flows 1½	+6	Chesapeake	
Naylors	386	1½	Flows 3	+45	Basal Pamunkey	Much water at 326 feet.

a +, feet above the surface; −, feet below the surface.

Partial list of deep wells—Continued.

Location.	Depth.	Size.	Capacity per minute.	Height to which water rises.	Horizon.	Remarks.
	Feet.	*In.*	*Gallons.*	*Feet.*		
Newcastle	187	1¼	Flows 10	+2		
Newport News	±600		None.		Chesapeake	
Norfolk	147	6?	Much.	—6	do	Very hard water.
Norfolk, Lambert Point.	610		65		do	Saline water.
Norfolk, Money Point.	562		Much.	+5	do	Ferruginous water.
North End Point	1,172		None.		Potomac	
Oak Springs	400	1¼	Flows 10–12	+6		
Onancock	140	4¼	5		Chesapeake	140–486 feet; no water.
Plum Point, 3 wells	168	1¼	Flows 10–12	+8–12	Basal Chesapeake	
Possums Nose	200				Potomac	
Providence Forge	80	1¼	None.		Chesapeake	Unfinished.
Puritan Bay, 2 wells.	215	1¼	Flows 10–12	+4–6	Basal Chesapeake	
Puritan Bay, 1 well	180	1¼	Flows 10–12	+4–6		
Quantico	350		4–5	Flows.	Basal Potomac	
Ragged Point	225	1¼	1	12	Basal Chesapeake	
Richmond:						
Paper mill	400		Fair.		Granite	Surface contamination.
Sherwood Park	900		None.		do	
Sherwood Park, 1 mile northeast.	250		None.		do	
Ginter's farm	400		Satisfactory.		do	Fine water.
Sandy Point:						
Westmoreland County.	235	1¼	3	+12	Basal Chesapeake	
Fairfax County	560		Satisfactory.	—24	Basal Potomac	No water below 270 feet; rock, 270–560 feet.
Sharps Wharf	235	1¼	Flows 12–35	+24	Basal Chesapeake	
Do	360				Pamunkey	Water also at 240 feet.
Sheppard's warehouse, 2 wells.	160	1¼	Flows 10–15	+6–8	Basal Chesapeake	
Swan Point	+100				Chesapeake	
Virginia Beach	70		Fair supply.		Upper Chesapeake.	Ferruginous water.
Walkerton, 2 wells	315	1¼	Flows 5–8	+4–6	Potomac	
Weems	260				Chesapeake	
West Point, 200 wells.	160	1¼	Average 12	Average +2.	Basal Chesapeake	
Whealtons	250		20		Basal Chesapeake?	
White House, 3 wells.	180–230	1¼	1–6	+5–20	Basal Chesapeake	
Williamsburg	876		None.		Potomac	
Do	280		Many.		Basal Chesapeake	Under hard rock stratum.
Windmill Point	430		None.		Near to basal Chesapeake.	To top of rock stratum.
Zuni	161		Flows 2		Chesapeake	

PIEDMONT PLATEAU.

The Piedmont Plateau extends from the Coastal Plain on the east to the foot of the Appalachian Mountains on the west. Its surface is made up mainly of more or less crystalline igneous or metamorphic rocks, but is marked by a number of basins of Triassic shales and sandstones.

Over the greater part of the Piedmont Plateau the uplands are smooth and rounded and the streams flow near their heads in broad, shallow valleys. In their lower courses the streams, especially the larger ones, have formed deep channels, and a strongly rolling topography has been developed. Toward the west the topography merges into that of the Appalachian Mountain belt.

Crystalline rocks.—The crystalline rocks of the Piedmont belt are deeply weathered at the surface and are broken by numerous joints that extend to considerable depths. As in similar regions elsewhere, the weathered upper portion everywhere furnishes supplies for shallow wells. Few deep wells have been drilled, but it is probable that moderate amounts of water would be obtained in a considerable percentage of the wells sunk. The water, however, would be likely in many instances to be rather strongly mineralized and unsuitable for some purposes. Moreover, because of the uncertainty of the presence of joints or other water-bearing fissures in the rock, the occurrence or nonoccurrence of water in a well at a given locality can seldom be predicted.

Triassic rocks.—The Triassic rocks consist of a series of shales and sandstones, with a few coals, etc., occupying basin-like depressions in the Piedmont Plateau. Moderate or small supplies of water are generally obtained by the shallower wells. Deeper wells would probably obtain considerable amounts in many instances, although, as in other Triassic areas, the waters are likely to be mineralized. Strong springs occur along certain of the faults which cut this area, and it is not improbable that flowing waters could be obtained in some localities.

APPALACHIAN MOUNTAIN BELT.

The term Appalachian Mountain belt is used in a broad way to include the entire belt of folded rocks lying between the Piedmont Plateau and the Cumberland and Allegheny plateaus of West Virginia and Pennsylvania. The rocks are of Cambrian, Silurian, and Devonian age, and include quartzites, sandstones, shales, and limestones. Near the eastern limits of the belt, separated from the Piedmont Plateau by only a narrow strip of folded rocks, is the Shenandoah Valley. This valley is underlain by Cambro-Silurian limestones.

The Appalachian Mountain belt is in general thinly inhabited and contains few wells. Springs abound and constitute the main source of supply of the inhabitants. The quartzites carry very little water in their denser portions, although springs of considerable size sometimes issue from their more porous parts. The springs of the shales are numerous, but are generally small. In the limestone area of the Shenandoah Valley, a region which is relatively thickly inhabited, dependence is placed largely on cisterns, the waters of the limestone being of uncertain occurrence. Near the borders of the limestone area, however, springs occur at some places, and it is probable that deep wells would often procure good supplies at these localities, but as the water sometimes occurs in definite underground channels successful wells would not always be obtained at such places.

The waters of many of the springs of the higher portions of the Appalachian belt are warm, and at a number of places the springs have been developed as resorts. At other springs the waters are bottled and sold for medicinal purposes. The association of these springs with anticlines was long ago pointed out by W. B. Rogers. It is not improbable that here, as in other regions, in some instances the locations of the springs were determined by faults.

CUMBERLAND PLATEAU.

The name Cumberland Plateau is applied to the elevated area of Carboniferous rocks lying northwest of the Appalachian Mountain belt. Only a small part of this area is included in Virginia, and that lies in the extreme western part of the State. The underground water supplies of this region are like those of the portion of the plateau included in Pennsylvania and Maryland. Practically no deep wells have been sunk, but it is probable that such wells if put down would obtain water from some one of the more sandy beds. It might even rise to the surface in synclines or other favorable situations. Springs are fairly numerous, but small.

COMMERCIAL SPRINGS.

During the year 1902 sales of water were reported from 48 springs, including representatives from each of the geologic divisions except the Cumberland Plateau. These are as follows:[a]

* Ætna Lithia Springs, Roanoke, Roanoke County.
* Augusta White Lithia Spring, near Augusta Springs.
* Basic Lithia Spring, Basic City, Augusta County.
* Bear Lithia Springs, near Elkton, Rockingham County.
† Beaufont Lithia Spring, Beaufont, Chesterfield County.
† Bellfont Spring, near Manchester, Chesterfield County.
† Berry Hill Mineral Spring, near Elkwood, Culpeper County.
* Blue Ridge Springs, Botetourt County.
† Buffalo Lithia Springs, Buffalo Lithia Springs, Mecklenburg County.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

† Chase City Mineral Springs, Chase City, Mecklenburg County.
† Como Lithia Spring, East Richmond, Henrico County.
† Coppahaunk Lithia Arsenic Springs, near Waverly, Sussex County.
* Cove Lithia Spring, Wytheville, Wythe County.
* Craig Healing Spring, Vista Craig, Craig County.
* Crockett Arsenic Lithia Spring, Shawsville, Montgomery County.
Diamond Spring, Norfolk County.
† Erup Mineral Spring, near Glen Carlyn, Alexandria County.
† Farmville Lithia Springs, Cumberland County, near Farmville, Prince Edward County.
† Fonticello Lithia Spring, Chesterfield County, near Richmond.
* Golindo Lithia Springs, Weyers Cave, Augusta County.
† Harris Anti-Dyspeptic and Tonic Spring, Burkeville, Nottoway County.
* Healing Springs, Healing Springs, Bath County.
† Houston Lithia Spring, Houston, Halifax County.
† Hume Springs, St. Elmo, Alexandria County.
* Hunter's Pulaski Alum Springs, Walkers Creek, Pulaski County.
† Jeffress Lithia Silica Springs, Jeffress, Mecklenburg County.
* Jordan White Sulphur Spring, Stephenson, Frederick County.
† Lone Jack Spring, Candless Mountain, Campbell County.
† Magee's Chlorinated Lithia Springs, Clarksville, Mecklenburg County.
† Massanetta Springs, Harrisonburg, Rockingham County.
* Montvale Hygeia Spring, Montvale, Bedford County.
* Nye Lithia Springs, Wytheville, Wythe County.
* O'Connell Lithia Spring, near Stribling Springs, Augusta County.
† Otterburn Lithia and Magnesia Springs, Amelia, Amelia County.
† Paeonian Spring, Paeonian Springs, Loudoun County.
† Pontiac (formerly Powhatan) Spring, near Falls Church, Alexandria County.
† Powhatan Lithia and Alum Springs, near Tobaccoville, Powhatan County.
* Rockbridge Alum Springs, Alum Springs, Rockbridge County.
* Rubino Healing Lithia Springs, Healing, Bath County.
* Seawright Magnesian Lithia Spring, near Staunton, Augusta County.
* Seven Springs, near Glade Spring, Washington County.
* Shenandoah Alum Springs, near North Mountain, Shenandoah County.
† Sublett's Lithia Spring, near Danville, Pittsylvania County.
† Swineford's Arsenic Lithia Springs, Osceola, Chesterfield County.
* Virginia Magnesian Alkaline Springs, near Staunton, Augusta County.
* Virginia Waukesha Lithia Springs, Staunton, Augusta County.
* Wallawhatoola Alum Springs, near Millboro Spring, Bath County.
† Wolf Trap Lithia Springs, Wolf Trap Depot, Halifax County.

Of these only the Diamond Springs of Norfolk County appear to be in the Coastal Plain. Of the remainder those marked * are in the Mountain belt, while those marked † are in the piedmont belt. The total output for 1902 was 2,442,398 gallons, having a value of $423,212.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 54-68.
Artesian-well prospects of the Atlantic Coastal Plain region, by N. H. Darton: Bull. U. S. Geol. Survey No. 138, pp. 162-190.

Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, p. 60.

Description of the Fredericksburg quadrangle, Maryland and Virginia, by N. H. Darton: Geol. Atlas U. S., folio 13, U. S. Geol. Survey.

Description of the Nomini quadrangle, Maryland and Virginia, by N. H. Darton: Geol. Atlas U. S., folio 23, U. S. Geol. Survey.

Description of the Washington quadrangle, Maryland, District of Columbia, and Virginia, by N. H. Darton and A. Keith: Geol. Atlas U. S., folio 70, U. S. Geol. Survey.

Description of the Norfolk quadrangle, Virginia and North Carolina, by N. H. Darton: Geol. Atlas U. S., folio 80, U. S. Geol. Survey.

NORTH CAROLINA.

By M. L. **Fuller.**

In North Carolina only two of the geographic and topographic belts recognized in Virginia are extensively developed. These are the Coastal Plain and the Piedmont Plateau. That part of the Appalachian Mountain belt which consists of folded sedimentary rocks is present only in the extreme western portion of the State. The Piedmont Plateau, however, becomes in this State mountainous as it approaches the former belt and topographically grades more or less imperceptibly into it. The Cumberland Plateau is not represented in the State.

COASTAL PLAIN.[a]

The geology of the Coastal Plain in North Carolina differs from that of Virginia principally in the reappearance of the marine Cretaceous beds, which thicken rapidly and rise to tide-water level and above nearly as far east as Wilmington. The Eocene formation thins somewhat, and in the southern counties lies almost entirely above tide level, on an irregular floor of marine Cretaceous sands and marls.

The Chesapeake beds thin rapidly southward, and lie mostly above tide level in shallow basins on the Eocene or marine Cretaceous.

The Potomac, the most important water-bearing formation of the Coastal Plain region, is best developed along the western border of this region in the counties southwest of the Neuse River—Harnett, Moore, and Richmond. In these counties the Potomac strata are exposed at intervals over a considerable area; and, dipping gently southeastward on the eroded surface of the crystalline rocks, doubtless carry considerable quantities of water. The Potomac formation also reaches the surface over limited areas, both north and south of Roanoke River above Weldon, and there are also outcrops of the formation at intervals between the Roanoke and Neuse rivers, but in this region the exposed areas of the formation are far less extensive than between the

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[a] Compiled from notes of J. A. Holmes published in Bull. U. S. Geol. Survey No. 138, 1896, pp. 190-193.

Neuse and the Pedee, and consequently the underground water supplies below the Tertiary marls of the counties between the Neuse and Roanoke will probably prove to be less abundant than in the more southerly counties.

The general geologic structure of the Coastal Plain in North Carolina is indicated in the accompanying section by Professor Holmes, fig. 20.

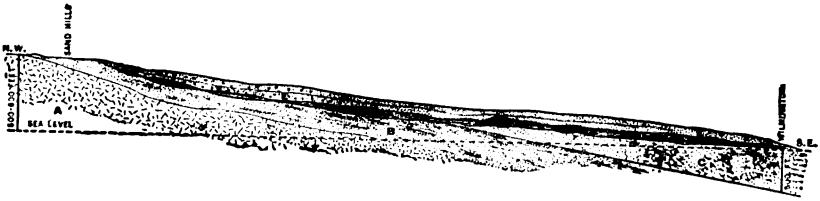

FIG. 20.—Cross section of the Coastal Plain region in North Carolina, from near Sanford to the coast near Wilmington. A, crystalline schists; B, Potomac sand, arkose, and clays; C, marine Cretaceous sands, marls, etc.; D, Tertiary marls and shell rock (Eocene and Chesapeake); E, Lafayette and overlying Columbia formation. Vertical scale greatly exaggerated.

It is not yet possible to present a review of the water horizons or of the well prospects in the State, but the following partial list of wells shows the results obtained by drilling at a considerable number of points.

Partial list of deep wells in the Coastal Plain region of North Carolina.

Locality.	County.	Depth.	Remarks.
		Feet.	
Elizabeth City, 10 wells	Pasquotank	64	Flow 15 gallons each; water hard and sulphurous.
Edenton	Chowan	340	No water.
Avoca	Bertie	180	Do.
Washington	Beaufort	140	Water not very satisfactory in quality.
Do	do	100	Do.
Do	do	360	No water.
Yatesville	do	215	Flows 50 to 60 gallons.
D. C. Way Lumber Co	do	300	Flows 15 gallons of sulphurous water; water also at 120 feet.
Roper	Washington	50-75	Yields 10 gallons of unsatisfactory water.
Lake Landing	Hyde	205	Pumps 15 gallons of fine water; water also at 85 feet.
Lake Comfort	do	115	Flows; water sulphurous.
Swanquarter	do	340	Flows a good supply of fine water from depth of about 86 feet.
Rose Bay	do	130	Flows good water.
Scranton, 3 wells	do	100, 160, and 195	Satisfactory water.
Middleton	do	212	Flows good water.
Fairfield	do	230	Flows.
Newbern	Craven	350	Pumps good water.
Do	do	50	Do.
Do	do	90	Do.
Springer Lumber Co	Pamlico	90	Pumps very hard water.
Beaufort	Carteret	200	Flows sulphurous water.
Jacksonville, 3 wells	Onslow	160	Do.

Partial list of deep wells in the Coastal Plain region of North Carolina—Continued.

Locality.	County.	Depth.	Remarks.
		Feet.	
Tarboro	Edgecombe	75	Flows 2 gallons.
Do	do	82	Pumps.
Do	do	160	Do.
Do	do	218	Flows.
Greenville	Pitt	200+	Water obtained, but pipe filled with sand.
Wilson Cotton Mills	Wilson	125	Hard water.
Goldsboro	Wayne	266	Quantity and quality satisfactory.
Kinston	Lenoir	115	Pipe filled with quicksand.
Lagrange (5 miles south)	do	57	Flowing well.
Warsaw	Duplin		In progess.
Burgaw	Pender	100	Water to near surface; quantity and quality satisfactory.
Longcreek	do	175	Stopped in quicksand.
Vineland	Columbus	63	Flows 4 gallons.
Do	do	225	Water nearly to surface.
Wilmington	New Hanover	495	Flows 75 gallons; very saline water.
Wilmington, 3 wells	do	84-100	Pump 400 gallons each of good water.
Hammocks	do	400	8-gallon flow of good water from 100 feet (?).

PIEDMONT PLATEAU.

The Piedmont Plateau lies between the Coastal Plain and the folded mountain belt, as in Virginia. The rocks are crystalline (igneous or metamorphic), and are characterized by basins of Triassic shales and sandstones similar to those in Virginia.

The topography is much the same as in Virginia, except that it is more rugged in the western portion next to the mountains. The crystalline rocks are even more weathered than in Virginia and are similarly broken by joints. Water in small to moderate amounts could probably be obtained almost anywhere within this belt, although large supplies are not to be looked for. It would rarely, if ever, rise to the surface, and is likely to be mineralized. The waters of the springs of the belt contain large amounts of mineral matter and are extensively used for medicinal and table purposes.

The Triassic rocks are somewhat similar to those in Virginia, and doubtless carry considerable water in their more porous beds. Very few deep wells, however, have been sunk in the Triassic areas.

APPALACHIAN MOUNTAIN BELT.

As has been indicated, only a part of the Appalachian Mountain belt lies within the State of North Carolina. The rocks represented are more metamorphic than those in the States previously described, and are frequently crystalline or semicrystalline. A few of the less metamorphic rocks also occur. The mountain belt in this State is relatively inaccessible and very thinly inhabited. The numerous springs which occur throughout the belt form practically the entire source of water supply of the inhabitants.

MINERAL SPRINGS.

The important mineral springs of North Carolina are located on the Piedmont Plateau. Of the 10 springs that report sales of water in 1902 only 1—the Seven Springs of Wayne County—is in the Coastal Plain. The following is a list of these springs:[a]

Alkalithia Spring, Alkalithia Springs, Alexander County.
Barium Rock Spring, Barium Springs, Iredell County.
Jackson Springs, Jackson Springs, Moore County.
Lemon Springs, Lemon Springs Station, Moore County.
Mida Spring, near Charlotte, Mecklenburg County.
Panacea Springs, near Littleton, Warren County.
Park's Spring, Caswell County, near Danville, Va.
Seven Springs, Sevensprings, Wayne County.
Thompson Bromine Arsenic Springs, Crumpler, Ashe County.
Vade Mecum Spring, Vade Mecum, Stokes County.

The total quantity of water sold in 1902 is given as 104,400 gallons, having a value of $18,795.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 74–78.

Artesian-well prospects of the Atlantic Coastal Plain region, by N. H. Darton [North Carolina, by J. A. Holmes]: Bull. U. S. Geol. Survey No. 138, pp. 190–207.

Preliminary list of deep borings in the United States, Pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, pp. 20.

Water resources of the Cowee and Pisgah quadrangles, North Carolina, by H. S. Gale: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, pp. 174–176.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

SOUTH CAROLINA.

By L. C. Glenn.

SUBDIVISIONS.

South Carolina is divided by a line running northeastward from Augusta, Ga., through Columbia, Camden, and Cheraw, S. C., into a Coastal Plain portion to the southeast and a Piedmont Plateau portion to the northwest. The Coastal Plain region is somewhat the larger of the two divisions and consists geologically of interstratified beds of sand, clay, and marl of Cretaceous or later age that are as yet mostly unconsolidated. The Piedmont Plateau region consists geologically of crystalline rocks whose exact age is unknown, although they are thought to be largely Archean or Algonkian. Because of this difference in their geology the water supplies and water-supply problems of the two sections of the State differ widely in their nature. Each section will be considered separately.

The climatic factors affecting the water supplies are simple and may be briefly stated. The annual rainfall varies somewhat from year to year, but averages about 50 inches and is almost uniformly distributed over the State. Autumn is the dryest of the seasons, receiving 2 or 3 inches less than its normal proportion of the rainfall, and in consequence streams are usually lowest in the late fall. Winter receives 2 or 3 inches more than its proportion. The streams of the Coastal Plain are never frozen over. During severe winters ice may occasionally form on streams in the inner part of the Piedmont region, but it lasts only a few days at a time and never becomes thick enough to interfere with the utilization of the streams for water power.

GEOLOGY AND WATER SUPPLY.

PIEDMONT PLATEAU.

GENERAL FEATURES.

Character.—Viewed broadly the Piedmont Plateau is essentially a plane surface with an average elevation along its outer or southeastern edge of 500 feet. It rises gently to the northwest to an average elevation of 1,000 feet along its inner edge. Beneath this general surface the main streams which flow southeastward have incised their courses 50 to 150 feet, and with their many tributaries have sculptured it into a gently rolling plateau that breaks into hills near the main drainage ways.

Rocks.—The rocks of the Piedmont Plateau consist of highly metamorphosed gneisses and schists, cut by granites and later intersected by many dikes, chiefly of diabase and presumably of Newark age. The gneisses and schists are regarded as pre-Cambrian in age. They have suffered such profound and repeated metamorphism that in very many cases their original character has been lost. Original bedding planes, if any ever existed, have been obliterated and planes of schistosity have been developed that have prevailingly a northeast-southwest strike and steep dips that range between southeast and northwest. In a few places narrow broken belts of crystalline limestone or of metamorphosed conglomerates indicate original sedimentary beds.

The granites are prevailingly coarsely crystalline to porphyritic, though some areas are of fine and uniform grain. They were intruded at various periods, all of which were probably pre-Cambrian, and have since been exposed at the surface by long and profound erosion, for it seems highly probable that the Piedmont Plateau has been a land surface since early Paleozoic time.

Residual soil mantle.—During all this time the disintegration and weathering of the crystalline rocks of the plateau has been in progress. During most of the time the solid rocks have been covered with a blanket of weathered material, which has at certain periods of uplift been largely removed to furnish material to build the Coastal Plain. At present a blanket of disintegrated material 50 to 150 feet thick overlies the solid rock over practically all of the Piedmont region. Much of this disintegrated material, especially near the surface, is a very fine-grained red clay, that makes the Piedmont streams a muddy red or yellow color.

WATER SUPPLIES OF PIEDMONT PLATEAU.

Effect of residual mantle.—The residual mantle plays an important rôle in relation to the water supply of the Piedmont region, for much of the rainfall is absorbed by it and held to be fed out gradually to springs and streams, thus making the stream flow more uniform than if the undisintegrated crystallines reached nearly to the surface. The main streams of the region have cut down through this blanket of disintegrated material to the solid rock beneath, which often shows in exposed ledges along their courses. Many of their tributaries have cut narrow valleys far back into the interstream area.

Springs.—Along the sides of the valleys, large and small, are found many unfailing springs, whose waters are usually free from mineral impurities of any kind. In the early settlement of the Piedmont region of South Carolina these springs were universally used for household water supplies. Wells and cisterns were unknown. The pioneer built his house near some bold spring, very often selecting a site on the hill slope or down in the small valley itself. Springs thus determined the location of the homes of the first settlers and for years continued to furnish practically the only water supply. They are used in very many cases to-day, and, in spite of the clearing of the land and the comparatively thick settlement of the country, have not failed or become polluted by man's presence, but they are still safe and satisfactory sources of domestic water supply.

There are a number of well-known mineral springs in the Piedmont region, at some of which hotels with good accommodations have long enjoyed wide popularity as summer resorts. The waters of these springs generally contain sulphates and carbonates of calcium, magnesium, sodium, and potassium. Some contain lithia and some are chalybeate.

The following springs,[a] all located within the Piedmont Plateau, reported shipments in 1902:

Buffalo Lick Springs, near Carlisle, Union County.
Chick Springs, near Taylor Station, Greenville County.
Cokesbury Mineral Spring, Cokesbury, Greenwood County.
Garrett Mineral Spring, Spartanburg, Spartanburg County.
Glowing Spring, near Calhoun Falls, Abbeville County.
Harris Lithia Spring, Harris Springs, Laurens County.
Rives Mineral Spring, Lancaster, Lancaster County.
West Springs, West Springs, Union County.
White Stone Lithia Spring, Spartanburg, Spartanburg County.

The aggregate amount of water sold is stated as 259,706 gallons, with a value of $76,525.

Open wells.—With increasing wealth and culture there came a demand for better building sites, and houses began to be erected back on the nearly level interstream uplands remote from springs, and the digging of open wells was begun. These open wells furnish the greater part of the water supply of the Piedmont region to-day. In some cases pure soft water is obtained before solid rock has been reached; in others water is obtained just on top of the solid rock, while in still others it is occasionally necessary to go into the solid rock some distance to a water-bearing seam. The wells of the Piedmont region range from 40 to 70 feet in depth, and they usually have from 5 to 10 feet of water, and rarely fail during dry seasons. The disintegrated material through which they are dug is not firm enough to be left unwalled, so that a curbing, usually of loose stone, is put in. In many cases not enough attention is paid to sanitary precautions, but as the water entering the well under the usual circumstances filters down through a considerable thickness of sand and clay, it is largely though not entirely protected from contamination. Occasionally one finds a bored well of 8 or 10 inches in diameter, though the dug well is far more common. These bored wells differ from the dug ones chiefly by being cheaper to sink, but they are more difficult to clean out.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

Deep wells.—Aside from the streams of the region the only possible source for considerable water supplies is the subsurface waters. The presence of granites and crumpled gneisses and schists in the region precludes the hope of securing deep artesian waters, for the structure of such rocks is unfavorable to artesian conditions.

Some Piedmont towns, however, moved by the idea that they could get artesian waters if they only bored deep enough have drilled wells several hundred feet into the crystalline rock, and, except in very few cases, have been rewarded with supplies of water that have risen to a height coinciding with the level of the ground-water surface in the rocks around the well, but such supplies are not artesian. The rocks of the region are traversed by seams and fissures, which everywhere below the ground-water level are filled with water. The deeply drilled hole has cut across enough such fissures to obtain a large supply of water for the pumps, yet this water is derived, not from a great depth nor from a long distance, but from the great body of ground water near the surface and immediately around the well. If the fissures in the solid rock are very numerous, the area supplying the water is an inverted cone whose apex is the lowest point of entry in the bore hole and whose base is a large circular area of the ground-water surface around the well mouth, and only one, two, or three score feet beneath the surface of the town, with its innumerable sources of pollution of every kind. If the well is supplied by only one fissure or by a very few fissures, they must be correspondingly larger and furnish more direct and easy lines of flow to the well. They may extend almost uninterrupted nearly up to the surface and furnish a direct channel for surface waters to enter the well.

The amount of water that can be pumped from such wells is usually large and analyses made when the well is first completed have shown a good, pure, clear, and usually soft water, well adapted to almost any purpose. But while at first such deep wells may be protected from contamination by the surface-soil layer, which acts as a filter, and the water may be pure and wholesome, yet they are very apt sooner or later to become contaminated. Constant pumping from them soon causes the indrafts supplying the water to open better channels through the fissures and allows more direct ingress of waters from the surface. These channels sooner or later are able to carry surface contamination directly into the well. Such deep wells are therefore at best open to grave suspicion and constantly need careful watching. This need is all the more necessary because of the fancied security given by the very favorable analysis of the water when first used. Such careful watching will usually result in the condemnation and closing of the well in a few years, especially if the town be of considerable size, so that there is furnished to the soil a large amount of contaminating organic material. A well of this kind drilled over 2,000 feet deep in Atlanta, Ga., some years ago, which at first furnished a large amount of acceptable water, was ordered closed by the board of health after a few years' use because of sewage pollution.

At Chester the first deep well sunk into the crystalline rocks failed to strike a single fissure, but was drilled perfectly dry 500 or 600 feet into a solid mass of porphyritic diorite. It was abandoned and a second attempt was made in another part of the town that was successful in striking a water-bearing fissure at 404 feet. A failure may at any time result from deep drilling in the crystallines, though as a general rule fissures are abundant enough to make it reasonably certain that water will be obtained in such wells at a reasonable depth.

Another source of water supply adequate for manufacturing plants or large institutions where only a few hundred thousand gallons are used daily, but usually not deemed sufficient for city supplies, is coming into use in the Piedmont region. It consists of tube wells, which are sunk usually in groups through the decomposed surface material down to solid rock, and which derive their supplies from water circulating slowly just on top of this rock. These wells are usually only a few inches in diameter and vary in depth with the depth of the surface disintegration, ranging from 30 to 80 feet in most cases. They are sunk along or near the lowest line of a natural valley or depressed area toward which a considerable surface area slopes, the larger the basin's extent, other things being equal, the larger the probable supply. Much of the rain falling in the basin percolates down through the soil and moves slowly along on the bed-rock surface, the slope of which usually coincides in the main with that of the soil surface above it. In some cases the clay soil near the surface may be so close grained as to act as an impervious covering for the water in the partly disintegrated and loosened rock beneath, so that wells sunk in this manner may be truly artesian—that is, they may have a natural flow caused by the pressure of the water confined beneath an impervious layer. The distance in this case from which the water comes is of course limited to the basin in which the well is sunk. It is a local artesian basin formed under exceptional conditions.

Such supplies of water have been found uniformly satisfactory. This result has of course been attained by selecting basins free from sources of contamination. The continued purity of such water will of course depend on the vigilance exercised in keeping the basin free from pollution. As such basins are ordinarily small this is not a difficult task. Several such wells in a group are usually connected and pumped together, and several such groups, if a sufficient supply is obtainable within a small area, would be sufficient to furnish with water a town of some size, or to aid materially in supplying a large city.

In York, Chester, Union, and Abbeville counties there are considerable areas of diabase or diorite that on weathering produce a close-grained clay soil that is abundantly charged with lime and magnesia. The springs and wells of these areas are accordingly of hard water. The use of cisterns is more necessary here than anywhere else in the Piedmont region, and yet they are the exception rather than the rule.

Streams.—Where larger supplies of water for manufacturing plants or town corporations are desired, resort is had in most instances to streams, and a pumping plant is installed to lift the water to a reservoir or standpipe. The streams of the Piedmont region are never perfectly clear except at their headwaters, among the mountain spurs that project from the Appalachians out upon the inner edge of the Piedmont area. The fine red clay soil, so characteristic of the deeply-weathered Piedmont surface, is washed into the streams in great quantities by every rain, and the waters become exceedingly muddy. So finely divided are some of these clay particles that they remain suspended indefinitely, and even with prolonged settling it is difficult or impossible to get the water perfectly clear. The excessive muddiness disappears very soon after the passage of a flood, but even in their lowest stages the Piedmont streams do not become perfectly clear. When they are used for city water supply, ample settling basins must be provided or a filtration plant must be installed. The clay is suspended in the water in particles so fine that it can be removed with difficulty even by filtration.

The most inviting sites for the location of towns in the Piedmont region have been the comparatively level interstream areas that form the divides between the main streams, and, as a rule, the principal towns of the region are both remote from and at a considerable elevation above the larger streams, thus occupying situations that greatly increase the cost of water supplies derived from such sources.

Furthermore, with the rapid growth of large cotton mills along these Piedmont streams, each with its attendant mill village in which the sanitation and the sewerage system are usually not what they should be, the problem of obtaining unpolluted water supplies from the streams of this region will constantly become more difficult.

With the growth of larger cities in the Piedmont area, however, other sources must in time become inadequate and the large streams must furnish the water supplies. Means must then be taken to provide sufficient settling area or adequate filter plants as well as to guard the watersheds of the catchment area from organic pollution. These water-supply problems are not different from those other communities have to face except, perhaps, as to the almost permanent suspension of the very fine clay particles, and can be successfully solved here just as they have been elsewhere.

COASTAL PLAIN.

The Coastal Plain attains a width of nearly 150 miles. The average elevation of its inner edge where it overlaps the Piedmont crystallines is about 500 feet. The slope of the surface from the inner edge toward the coast is at first rather steep, so that 30 miles from its inner edge the average elevation has decreased to less than 200 feet. From this line to the sea the surface slope is very gentle. Much of the outer part of the Coastal Plain is low and swampy and the rivers crossing the region are usually fringed with swamps that are in places 5 to 10 miles wide.

The inner, more elevated portion of the Coastal Plain is deeply trenched by the rivers that enter it from the Piedmont region, and much of its surface has been cut into hills by the tributary streams that drain it. An inner belt of these hills is known as the *sand hill* belt; an outer interrupted belt that is in places more broken and hilly than the preceding one is known as the *red hill* belt.

GEOLOGY.

Crystalline floor.—Along the outer edge of the Piedmont Plateau the surface of the crystalline rocks dips southeastward and passes beneath the overlapping sands and clays of the Coastal Plain. From well records something has been learned of the depth of the crystalline floor beneath the surface of some parts of the Coastal Plain; but much more information is desirable concerning its depth, especially beneath the central and southwestern parts. At Aiken a boring, after passing through 465 feet of sands and clays, reached granite at 62 feet above sea level. At Florence 608 feet of Coastal Plain sediments overlie the rocks of the Newark formation, which were reached at 473 feet below sea level. At Marion a boring that passed through 700 feet of sands and clays entered crystalline schists 632 feet below sea level. At Wilmington, N. C., a well started only a few feet above tide entered granite at a depth of 1,109 feet. At Orangeburg a well 1,160 feet deep had not reached the crystallines, but was probably not far above them. A well at Charleston 2,050 feet deep and one at Beaufort 1,640 feet deep failed to reach the underlying crystallines.

General character of deposits.—The Coastal Plain formations consist of fine gravels, sands, clays, marls, and an occasional soft limestone. The dip of the lower members is southeastward at a rate somewhat greater than the surface slope. The higher members, however, thicken seaward until the youngest members, or those at the top, dip at the same rate as the surface.

Potomac formation.—The oldest of these members is the Potomac. It lies immediately upon the crystallines, and along its outcropping inner edge consists of at least 400 or 500 feet of variegated sands and clays. Much of the sand is coarse and cross-bedded, and usually contains a considerable amount of arkose. The clay is in very irregular lenticular masses embedded in the sands and does not form continuous and persistent strata. These sands and clays outcrop in the sand hills and in part of the red hills along the inner edge of the Coastal Plain in a belt 5 to 10 or more miles wide, where they receive the supplies of water that they carry seaward with them beneath the later members of the Coastal Plain series. These Potomac sands and clays are water-bearers under very much, if not all, of the Coastal Plain; but very little is known as to their exact depth beneath the surface in much of the region. A 1,160-foot well at Orangeburg had probably reached nearly to their base. At Florence they extend from 200 or 300 feet to 607 feet. At Charleston the 2,050-foot well probably stopped in their upper portion. It is probable that the 1,640-foot well at the naval station at Port Royal had just about reached their top layers, and it is likely that a supply of good water might have been obtained in these Potomac sands within the next few hundred feet had the well not been abandoned where it was. The water found in the deeper-lying portions of the Potomac under the outer part of the Coastal Plain may, however, be found charged more or less with mineral matter, although the water from the deep wells at Charleston is reported to be of excellent quality and furnishes the city's supply.

Marine Cretaceous beds.—The marine Cretaceous is the next younger formation. It consists of dark, unctuous, fine-grained clays, locally known as fuller's earth, and often described by the drillers as soapstone, interbedded with fine, light-colored micaceous sands. The clays contain abundantly disseminated iron pyrite that readily decomposes and gives rise by further reaction to alum, so that open wells and springs in these clays are sometimes very astringent. These Cretaceous clays outcrop only in the eastern part of the State. They do not form the general surface even here, but are overlain by a thin mantle of younger deposits, and are revealed only in stream cuttings along the Pedee and its tributaries. The best exposures are in Darlington and Florence counties. West of Lynches River the marine Cretaceous is not known to outcrop at the surface. There the Eocene rests directly on the Potomac.

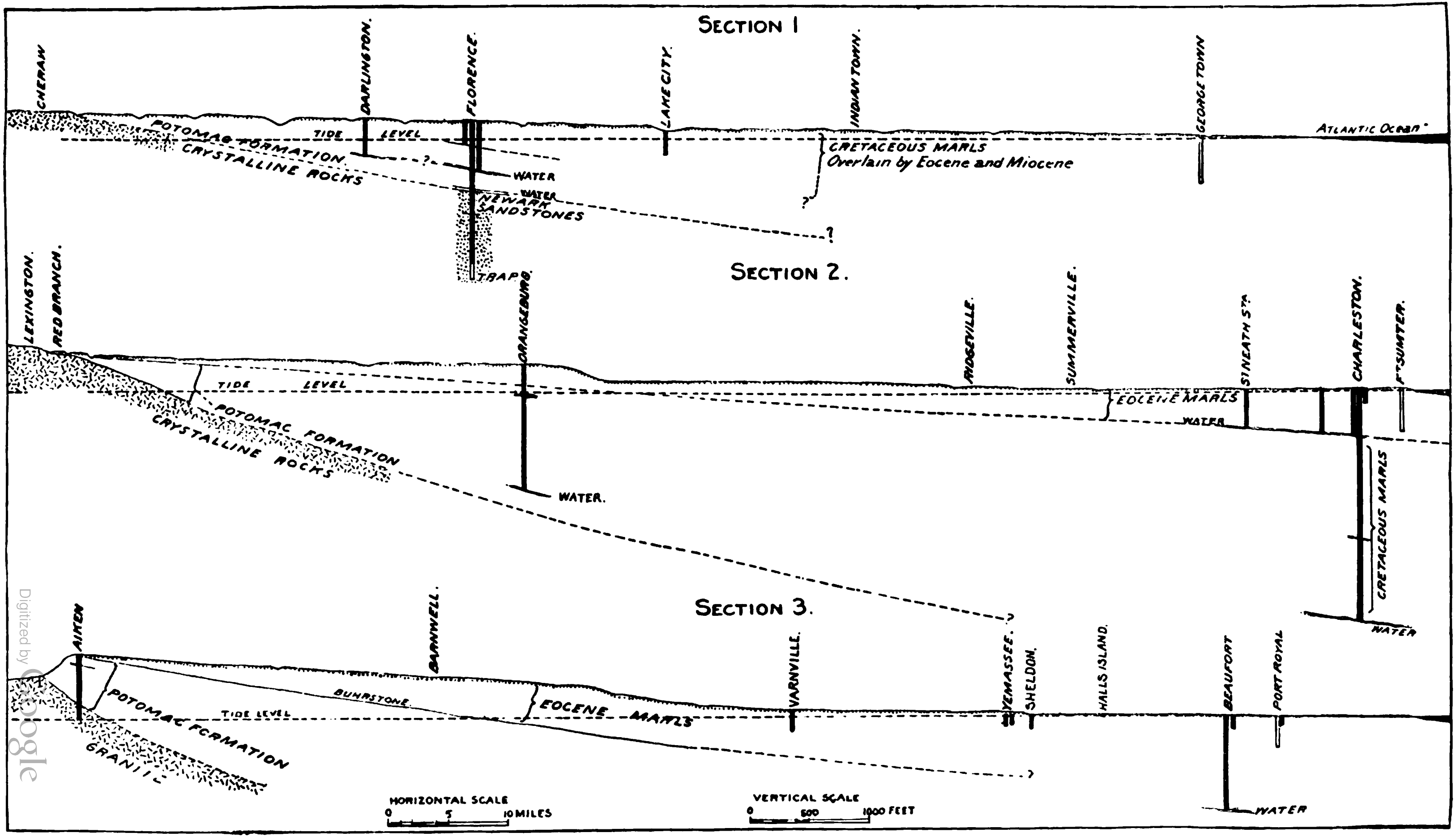
From its surface exposures in the eastern part of the State the marine Cretaceous dips southeastward beneath later deposits, and is reached or passed through in the deeper wells of that region. It extends from about 600 to about 1,900 feet in the Charleston wells. It was passed through in the Orangeburg well, its top being about 252 feet from the surface, and its bottom being indeterminate from the record obtained. The Port Royal well from 700 or 800 to about 1,600 feet is in the marine Cretaceous. Well records show that it consists of sands, marls, and dark clays, the latter sometimes described as very tough and sticky to drill. The layers of sand occupy no definite horizon. They are usually water-bearing, but the water is often charged with sulphur or iron or is brackish or salt. No persistent horizon of potable water is known in this series. Some of the sandy strata may, however, locally contain good water, and careful tests for quantity and quality of water should be made at any promising horizon.

Eocene deposits.—The Eocene overlies the Cretaceous. In the eastern part of the State, where the Cretaceous is exposed in stream cuttings, a few thin, isolated patches of Eocene are found resting in depressions in the Cretaceous surface. West of Lynches River the Eocene rests directly on the Potomac, and in Orangeburg, Lexington, and Aiken counties numerous exposures of it occur. At the base it consists of fine, light-colored siliceous clay, breaking with conchoidal fracture, and overlain by a silicified mass of shells and casts—the Buhrstone. Above it are soft gray to white pulverulent, calcareous marls, whose lower part is known as the Santee marls, and whose upper part is the Ashley and Cooper marls. They may be grouped together here. These Eocene strata are probably 500 feet thick at Charleston and occupy a basin called the Charleston basin, delimited to the northeast by the marine Cretaceous strata, which come to the surface in the Pedee region, but are of unknown extent to the southwest in Georgia, though they rise considerably in Barnwell County.

The Buhrstone division of the Eocene is more or less cavernous and is generally water bearing. The waters, as might be expected, are more or less hard. They are reached at Charleston at about 400 to 500 feet from the surface. At Orangeburg the base of these rocks is probably about 252 feet from the surface. In Bamberg, Barnwell, Colleton, and Hampton counties they seem to be widespread water bearers and are reached at depths of about 100 feet in upper Barnwell, but dip toward the coast so that there they are found at 500 to 700 feet from the surface. The basal Eocene is therefore very generally water bearing and lies at moderate depths beneath that large portion of the Coastal Plain in which the Eocene occurs. No definite water-bearing horizons are known in the overlying Eocene marls. Open wells and springs in these upper beds furnish hard water.

Miocene marl.—A thin stratum of late Miocene shell marl rests in many places on the eroded surface of either the Eocene or, in the Pedee region, the marine Cretaceous. It is not usually widely continuous and is not important as a water-bearing horizon. Open wells sunk to it yield hard water. It rarely outcrops, and so produces but few springs.

Lafayette and Columbia sands.—Along the inner and more elevated red hill and sand hill portion of the Coastal Plain there may be discriminated in most cases two thin formations of sand that blanketwise overlie all of the older formations. The older one is usually a hardened, cross-bedded sand, often carrying considerable clay and near the rivers, as they enter the Coastal Plain, contains rounded pebbles



SECTIONS IN EASTERN SOUTH CAROLINA.

and cobbles. It is regarded as of Lafayette age. Where it overlaps on the Potomac sands and clays it is in many places very difficult to determine the contact line so very similar are their materials, the Lafayette being derived in such cases from the underlying Potomac by a slight reworking. These Lafayette sands and clays are usually red in color. In Columbia they are homogenous, structureless, and bright red. In many places they are mottled red and light gray. They form much of the surface in the "red hill" belt. In the middle and outer half of the Coastal Plain the Lafayette has not been discriminated. If ever present in the outermost part, just near the present coast line, it has very probably been removed by erosion, for the post-Pliocene rests on rounded phosphate nodules that cover the surface of the Eocene or Miocene marls from which they were torn by the waves.

The younger of the two blanketing formations is a light-colored, soft, clean-washed, barren sand that forms the surface of most of the Coastal Plain, including the sand hills. In the middle and outer part of the Coastal Plain it is usually mixed with enough clay to form a loam.. In thickness it ranges from a few feet up to perhaps 50 feet in some places near the coast. It is regarded as of Columbia age, but such distinctions as high-level and low-level or fluvial and interfluvial seem inapplicable to it. Its relation to the post-Pliocene deposits indicates that the portion near the coast, at least, is of late Columbia age.

The post-Pliocene, which comes between the Lafayette and the Columbia, is found in places along or in a few miles of the coast. It is a thin stratum of sand and shells and is of no special importance as a water bearer.

WELLS.

The following tables present a comprehensive summary of the results of numerous wells bored in the Coastal Plain of South Carolina. Since the list was made a considerable number of new wells have been drilled, but the present table is nevertheless fairly representative:

Partial list of deep wells in South Carolina.[a]

Locality.	Depth.	Diameter.	Capacity per minute.	Height of water.[b]	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Feet.*	
Abbeville	520	....	Many.	− 3	In ancient crystallines.
Aiken	558	8–6	50	−170	In granite; water also at 543 feet.
Bamberg:					
30 wells	65-100	....	....	....	In buhrstone.
5 wells	470 495 520 555	2 2 2 1¼	40 35 35 40	+ 15 + 20 + 12 + 30	In Potomac sands.

[a] Darton, N. H., Artesian-well prospects in the Atlantic Coastal Plain region: Bull. U. S. Geol. Survey, No. 138, pp. 210–211; also records collected by the writer.

[b] +, feet above surface; −, feet below surface.

Partial list of deep wells in South Carolina—Continued.

Locality.	Depth.	Diameter.	Capacity per minute.	Height of water.	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Feet.*	
Barnwell					
Beaufort:					
Coosaw Company	800				
Water works	120	10	Many.	Does not flow.	
Blacksville	120				
Bluffton. (See Mays River.)					
Camden, 2 wells	618, 625			−20	Water fine. Granite below 82 feet.
Charleston, 6 wells	1260–2000	2½–6	170–800	+4 +25	Saline water.
Charleston, 9 wells	323–475				
Chester	500	8			Perfectly dry hole. In diorite.
Do	404?	8	Many.	Does not flow.	In diorite. Depth also given as 372 feet.
Clyde	152				In Potomac sands.
Connors	630+	6–2			Drilling.
Conway, several	210–240		30	Flows.	Some sulphur.
Darlington	327		30	To surface.	In Potomac formation.
Cotton factory	280	2	10	Flows.	Water from 212 feet.
Denmark	450			Pumped.	Water from 150 feet.
Estill	850			Flows.	
Eutawville	350		Few.	Flows.	
Do	100	2	Many.	Pumped.	
Florence, city works	1,215	10–8	100	− 20	608 to 1,335 feet in Newark sandstone; waters also at 600 and 800 feet.
Do	182			− 24	
Florence, Ice works	200		Many.		Fine water.
Florence, Machine shop	420	Small.	Many.		Do.
Fort Fremont	429				
Fort Motte	141				Abandoned in quicksand.
Grahamville, 2 wells	121	6	170	Flows.	Another well is 164 feet deep.
Do	220	2	Few now.		Water at 170 feet.
Do	220	4	Few now.	Flow.	Hard water, water at 170 feet.
Do	350	4	Few now.	Flow.	Hard water; water at 250 feet.
Georgetown	570		50–60	+10	
Georgetown, 10 wells	65–74	2	Many.	− 4	8 feet of water.
Green Pond	503	3	1	Flows.	Temp. 70° F.
Greenwood	400	8	4	− 4	In ancient crystallines.
Halls Island, Donner Bros	120	6	150	+20 above high water.	Sulphurous water.
Hampton	583	6	Many.	− 9	Soft, irony water.
Do	186			− 3	
Do	46		1 in. stream	+ 4	Irony water.
Do	800?			Does not flow.	
Hartsville, 8 wells	228–240			− 8	In Potomac sands.
Jacksonboro	420	3	4	Flows.	Temp. 72° F.
Johns Island	500	6	11	Flows.	Temp. 70° F.
Kingstree, 3 wells	320	2	Many.	Flows.	Fine water.
Lake City, 10 wells	160–320	3 and 2	7–15	+15	
Manning	375	2	2		Soft.
Marion	1,244	8–9	¼	Flows.	Small flow at 700 feet on top of crystallines.
Moncks Corner	179	2	35	−14	16–148 feet in line with flint rock below.

Partial list of deep wells in South Carolina—Continued.

Locality.	Depth.	Diameter.	Capacity per minute.	Height of water.	Remarks.
	Feet.	*Inches.*	*Gallons.*	*Feet.*	
Moncks Corner, 8 miles distant.	175	2	15	Flows.	
Mays River, Bluffton.........	165	....	Many.	....	
Mays River, Capt. T. R. Hayward's place.	800	....	Fair.	– 1	Very sulphurous water.
Mays River, Col. J. H. Estill's place.	190	....	Many.	....	Sulphurous water.
Mays River, Col. J. H. Estill's plantation, 4 wells.	360	....	Many.	Flows.	Fine water.
Mays River, Snyder & Mittle's sawmill.	106	....	Many.	Flows.	Do.
Newberry	285	....	....	Nearly to surface.	In granite.
Oakley Depot	299	2	Many.	Does not flow.	Fine water.
Orangeburg, 4 wells..........	1,160	....	Many.	–48	Much water at 250 feet.
Ousley.........................	380	....	Not any.	....	In Potomac sands.
Palmetto	346	2	6	Nearly to surface.	
Peeples.	853	6	100	Flows.	Temp., 76° F.
Port Royal Naval Station.....	255	6	Very few.	Does not flow.	Water very impure.
Port Royal Naval Station, 3 wells.	60	5 and 2	Many.	–12–16	Water hard and saline.
Port Royal Naval Station, 2 wells.	95–98	6	125	Pumped.	Good water.
Do.........................	1,640	15–4	....	....	Abandoned in Cretaceous clays.
Rowesville	185	3	....	–6	Hard water.
St. Matthews, 5 wells.........	75–135	3	....	Do not flow.	Excellent water.
Scranton	170	2	....	Flows.	
Seabrook	120	6	150	+12	A little H_2S.
Shelden	152	3	Many.	Does not flow.	On high land.
Sullivans Island, Fort Moultrie.	1,308	12–3	10	Flows.	Temp., 89° F. Contains iron and soda.
Sumter	128	2	2	Flows.	Soft water.
Swansea.......................	100?	....	....	....	
Union	300+	....	....	....	Drilling. In granite.
Varnsville.....................	988?	6	Many.	–17	
Walterboro	490	6	Many.	–30	Soft water.
Wedgefield	580	3–2	....	–90	Not used.
Williston, L. Green...........	130	3	5	....	
Yemassee, G. G. Martin	90	4½	Many.	Flows to +13.	Sulphurous water.
Yemassee, J. B. Gregorie, 8 wells.	85–150	6	Many.	+8	Sulphurous water; flow decreasing.

SUMMARY OF COASTAL PLAIN SUPPLIES.

Shallow wells.—The shallow wells of the Coastal Plain are sunk in the surficial Lafayette and Columbia formations. These wells are usually not over 20 or 30 feet deep. Many, indeed, are from 8 to 12 feet deep, and in wet weather many of them are entirely full of water. Such surface water is as a rule impure and unwholesome, especially if the wells be open. Driven wells are now largely taking the place of open wells. A 2-inch pipe tipped by a sharp-pointed strainer section is driven from 15 to 30 feet, and a small suction pump is attached to the upper end. Such wells are quickly, easily, and cheaply driven, and do not permit surface waters to trickle down directly from the surface, as do the open wells. Their waters are more wholesome than those of open wells, but their general use will not solve the pure-water problem for the Coastal Plain.

Deep wells.—Many farmers are sinking artesian wells of small diameter and moderate depths to the upper part of the Potomac beds in the inner half of the Coastal Plain, while on the outer half wells are bored deeper with somewhat less certainty of getting good water from the lower Eocene. Unfortunately, very few records that give much information as to the age or kind of beds passed through have been kept by the drillers or owners, so that our knowledge of the underground waters of the region leaves much still to be desired. Experience, however, has proved that in many parts of the Coastal Plain the chances for obtaining supplies of deep water that will rise nearly to or just above the surface are excellent. In other parts, especially very near the coast, the problem is more uncertain because of the great depth of the water-bearing strata and the greater risk of finding the water too highly impregnated with various mineral matters to be usable. Numerous good wells, however, have been drilled near the coast, and drillers in this region should carefully test every water-bearing sand of any promise as they go down.

The use of artesian water has greatly improved the health conditions on the Coastal Plain. Not only has typhoid fever been banished, but of greater importance, because of its former more general prevalence, malaria has been practically banished also, despite the presence of mosquitoes.

Streams.—The streams of the flatter portions of the Coastal Plain are dark wine-colored from the presence of organic matter. Those in the sand hills are usually pure and clear and may be used for bleaching or for any other similarly exacting purpose for which a very pure, clear water supply is necessary. The sand hills yield their underground waters very gradually and regularly to the streams, so that stream discharge in this region is very uniform.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 79-80.

Artesian-well prospects of the Atlantic Coastal Plain region, by N. H. Darton: Bull. U. S. Geol. Survey No. 138, pp. 207-222.

Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, p. 43.

Year Book, City of Charleston, 1881, pp. 257-315.

GEORGIA.

By S. W. McCallie.

Georgia may be divided into three great provinces—the Coastal Plain, the Piedmont Plateau, and the Appalachian or Paleozoic area—each of which represents a great time division of geologic history.

COASTAL PLAIN.

The Coastal Plain includes that part of the State lying south of an irregular line connecting Augusta, Macon, and Columbus, and comprises more than one-half of the entire State. In this region the rocks are Cretaceous and Tertiary clays, sands, and soft limestones, having a general dip southward of only a few feet to the mile. The sands and limestones usually furnish copious supplies of water, which in some instances has sufficient head to be used for irrigation purposes and to operate machinery. The waters from the Cretaceous beds are usually soft, but those from the Tertiary are frequently hard and unsatisfactory for many purposes.

In addition to the underlying Cretaceous and Tertiary formations two surficial formations—the Lafayette and the Columbia—are of especial importance in connection with the water supply of shallow wells. These formations consist of clays and sands, and cover more or less completely the entire Coastal Plain. The Lafayette, the older of the two, lies unconformably on the Cretaceous or Tertiary rocks. It consists of orange and vari-colored sands and clays with local beds of gravel. Overlying the Lafayette is the Columbia formation, which is made up almost entirely of rather fine-grained sand, and in places attains a thickness of many feet, but more often is much thinner, or is entirely wanting. These two surficial deposits are the main sources of the water supplying the shallow wells throughout the Coastal Plain, and they also govern the amount of rainfall taken up by the underlying Cretaceous and Tertiary sands and limestones. Where the Lafayette formation consists largely of clay it forms an impervious water-bearing stratum which to some extent prevents rainwater from penetrating the underlying Cretaceous or Tertiary deposits. On the other hand, the Columbia sands absorb a large percentage of the rainfall, which is retained until taken up by the underlying deposits. These surficial formations either increase or decrease the water supply in deep wells according as they take up little or much of the rainfall.

PIEDMONT AREA.

The Piedmont Plateau, or crystalline area, embraces all of that part of the State lying north of the Coastal Plain with the exception of the greater part of ten counties in the northwestern portion.

This region is an old eroded land surface, formed of highly metamorphosed igneous and sedimentary rocks, which are frequently weathered to considerable depths. The prevailing rocks are slates, schists, gneisses, and granites, none of which can be considered water-bearers of any great promise. The crystalline area is noted for the numerous small springs that are rather evenly distributed throughout it. There are a few large springs, but they are rare and are usually due probably to the presence of faults rather than to any special water-bearing strata. The deep weathering of the rocks is favorable to a copious supply of water for shallow wells. Nearly all of the small towns are supplied by such wells, which, except during an extremely dry season, furnish an abundant supply of what is generally supposed to be very wholesome water. Deep wells have been drilled by some of the towns, but in the majority of cases the amount of water secured has been inadequate to supply the demand. Furthermore, the geologic structure of the crystalline area is such that water obtained from deep borings is likely to become contaminated sooner or later from surface drainage, especially where there is little or no sandy soils to act as a filter, and where the upturned edges of the rocks dip at a high angle.

APPALACHIAN OR PALEOZOIC AREA.

The Paleozoic area comprises the greater part of ten counties in the extreme northwestern part of the State. The rocks of this region are limestones, shales, and sandstones, thrown into a number of long parallel anticlinal and synclinal folds. The anticlinal folds in many cases have been decapitated and are now replaced by valleys of erosion, while the synclines form the intervening ridges or mountains. These structural conditions are usually unfavorable for flowing wells, but at the same time they materially allow the rainfall to be rapidly absorbed by the upturned edges of the strata. They also explain the distribution of the numerous springs.

The water-bearing strata of the Paleozoic area are the limestones and the sandstones. The limestones, from which most of the underground water is obtained, are usually heavy bedded and compact. The water contained in them frequently occurs in deep fissures or channels as running streams of considerable size.

When these strata outcrop such streams give rise to huge springs, which furnish large volumes of water, and which often occur throughout the Paleozoic area. The largest of these springs are generally found along fault lines or near the contact of limestones with impervious shales. The water from these large springs often becomes muddy after a heavy rainfall, showing that the underground stream which supplies them with water has direct connection with limesinks or other open cavities on the surface. Such springs are also more or less affected by droughts, and have been known to entirely cease flowing during an extremely dry season.

The sandstones of the Paleozoic area which are here spoken of as water-bearing strata are confined chiefly to Sand and Lookout mountains. At several points on these mountains the bore holes put down in prospecting for coal have furnished rather copious supplies of water. The numerous coal mines located on these mountains also demonstrate that the sandstones are water carriers of considerable importance. In northwest Georgia are also very favorable conditions for shallow wells. The residual clays are generally of such thickness as to retain a high percentage of the rainfall within a short distance of the surface and supply shallow wells with ample water for all domestic purposes.

UNDERGROUND WATER CONDITIONS.

The geologic conditions bring out prominently marked differences in the underground water conditions of the different parts of the State. In south Georgia, or the Coastal Plain, the numerous beds of sand and porous limestones with their gradual dip southward present favorable conditions for deep wells. In the crystalline and Paleozoic areas, where the formations are much folded and faulted, underground water reaches the surface by numerous springs. In the one case the deep-seated underground waters reach the surface through artificial openings made by the drill, and in the other they come up through open fissures or along bedding planes of the rock. In the first case the underground waters are far more liable to become contaminated by surface impurities than in the other. This is due to the high or steep dip of the water-bearing strata. In south Georgia the underground waters in most cases probably flow through several miles of porous limestones or sands before reaching the deep wells, but in the northern part of the State wells equally as deep may be supplied with water falling as rain only a few hundred yards distant.

The conditions governing the water supply of shallow wells are practically the same in all parts of the State, especially where the wells obtain water from surficial deposits and residual clays.

The water from the shallow wells supplying small towns in north Georgia was usually found to be in fair sanitary condition, but in a few instances analyses made in the laboratory of the State geological survey gave unmistakable evidence of sewage contamination. Certain local geologic conditions, which are peculiar to the northern portion of the State, seem to be the cause of this contamination. They will be described somewhat in detail.

All of the rivers and large streams throughout the crystalline and the Paleozoic areas traverse valleys of erosion which vary in width from a few hundred yards or less to a mile or more. These valleys, parts of which now lie several feet above the present flood plain of the river, are often covered to the depth of many feet with alluvial deposits left by the stream when it flowed at a higher level. The deposits usually occur in two layers. The lower layer, which lies directly upon the eroded edges of the underlying rocks, consists

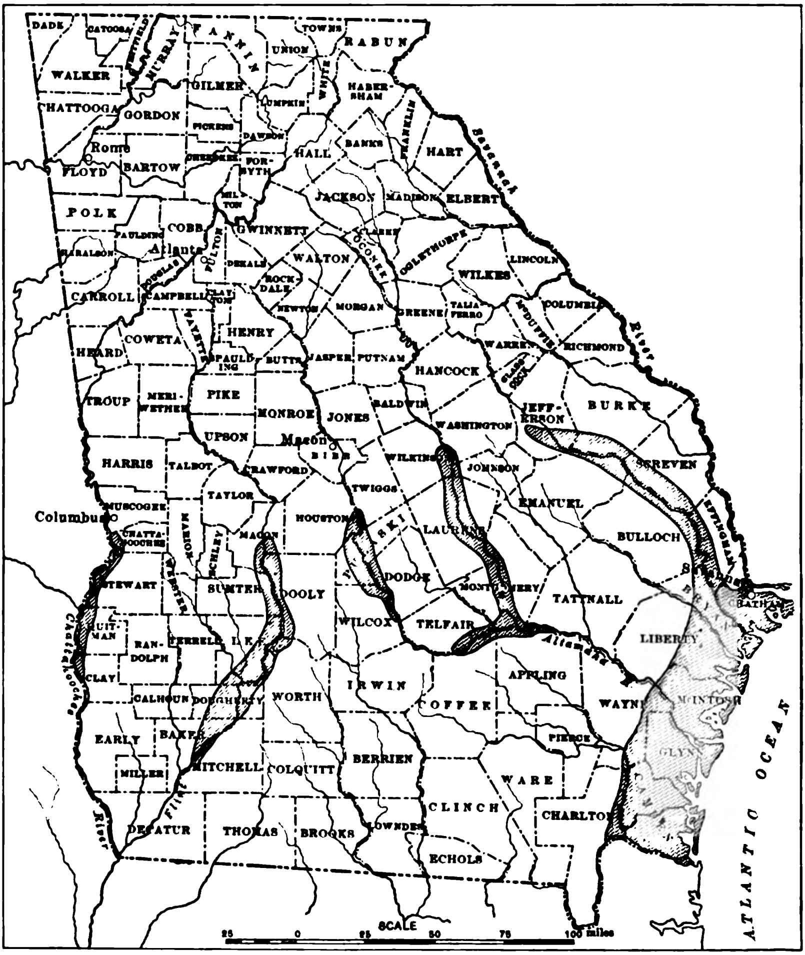


FIG 21.—Areas of flowing wells in Georgia. Flowing wells may be obtained in shaded areas.

chiefly of coarse waterworn gravel and rounded stones, the latter often attaining a weight of many pounds. The thickness of this layer is variable and depends somewhat upon the irregular eroded surface of the underlying rock, but generally it is from 10 feet to a few inches. The upper layer, which is usually much thicker than the lower, is made up largely of silt or sandy clays. The two layers are conformable and have the same dip as the eroded surface of the underlying rock. This gives to the entire surficial deposit a gradual slope toward the center of the valley or the present channel of the stream. In many places the upper of the two surficial beds has been removed by erosion along the edges of the valley so that the underlying gravel is exposed. These exposed edges of the gravel beds present most favorable conditions for taking up the surface waters as they escape from the adjacent hillsides to the valley below after hard showers. These beds form a very imperfect filter and, as a consequence, the well water obtained from them is liable to become contaminated by surface impurities.

In north Georgia some of the towns along the rivers depend for water supply almost entirely upon surface wells penetrating these gravel beds. In laying out such towns it has been the custom to locate the business houses and the residences near the center of the valley, and the barns and stables along the margin near the outcrop of the gravel beds. In one town a row of factory houses was built along the outcrop of these gravel beds and there was an epidemic of typhoid fever throughout the town. Another town where the well waters were contaminated had suffered from a most violent epidemic of typhoid fever a few years previous. With a comparatively small outlay all of these towns can be supplied with excellent water from the mountain streams.

MINERAL SPRINGS.

Ten springs in Georgia reported sales of water in 1902. The total amount sold was 419,100 gallons, valued at $60,797. The springs are as follows:

Artesian Lithia Well, Austell, Cobb County.
Bowden Lithia Springs, Lithia Springs, Douglas County.
Catoosa Springs, Catoosa County.
Daniel Mineral Spring, near Union Point, Greene County.
Hughes Mineral Springs, near Rome, Floyd County.
Medlock Lithia Springs, Austell, Cobb County.
Ponce de Leon Spring, near Atlanta, Fulton County.
Salt Spring Lithia Well, Austell, Cobb County.
Siloam Healing Springs, near South Atlanta, Fulton County.
Sulpho-Magnesia Lithia Spring, near Austell, Cobb County.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. PEALE: Bull. U. S. Geol. Survey No. 32, pp. 81–85.

Artesian-well prospects of the Atlantic Coastal Plain region, by N. H. Darton: Bull. U. S. Geol. Survey No. 138, pp. 222–224.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 22–24.

Preliminary report on the artesian-well system of Georgia, by S. W. McCallie: Bull. Georgia Geol. Survey No. 7, 1899.

Georgia [well and spring records and town water supplies], by S. W. McCallie: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, 1904, pp. 207–237.

Experiment relating to problems of well contamination at Quitman, Ga., by S. W. McCallie: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, 1905, pp. 45–54.

FLORIDA.

By M. L. Fuller.

Florida, unlike any other State except Louisiana, lies wholly within the Coastal Plain, although Delaware and Mississippi include only very small areas of older rocks. While in both geology and topography it resembles certain portions of the Coastal Plain region in other States, it is, as a whole, unique in its characteristics.

TOPOGRAPHY.

The relief of Florida is the lowest of any of the Eastern States, only about a quarter of its area standing above the 100-foot level, while only a few isolated points exceed 200 feet in height. Starting in the western portion of the State the highland belt skirts the northern boundary to Tallahassee, beyond which it extends southward along the center of the peninsula to a point east of Tampa. Its eastern border stretches northward a few miles west of St. Johns River to the northern boundary of the State northwest of Jacksonville. In this region soft limestones occur extensively, and there are, especially in the peninsula, many sinks and depressions, which are frequently occupied by ponds, lakes, or marshes. It is the gathering ground of the flowing waters encountered in the wells nearer the coast. On each side of the highlands the land slopes toward the coast, becoming at the same time freer from sinks and similar irregularities, but more or less cut by stream channels. Along the coasts on both sides of the southern portion of the peninsula are numerous low-lying islands or reefs of coral, shell fragments, or other material. The interior of the southern portion of the peninsula is occupied largely by vast swamps, of which the Everglades is the most extensive and best known.

The population is largely confined to the highlands. There are a few cities and villages near the Gulf coast west of the Tallahassee region and a considerable number about Tampa Bay. The Gulf coast is otherwise thinly inhabited. On the Atlantic side there is a line of villages and towns along the coast, but south of Titusville the interior is largely uninhabited. Key West and a few villages and towns are located on the keys and islands.

GEOLOGY.[a]

The axis of the peninsula of Florida consists largely of rotten cavernous limestone, white, gray, or yellow in color and of the Tertiary age. The main belt of these beds extends from the vicinity of Taylor, Madison, and Suwanee counties southeastward to Pasco County and vicinity. On the west the Lower Oligocene limestones are separated from the coast by a strip of Upper Oligocene beds, consisting of somewhat harder and more massive limestones with occasional beds of clay. The Upper Oligocene beds extend northwestward parallel with the Gulf shore to the western limits of the State. On the east the Lower Oligocene belt is limited by Octawaha River, beyond which are beds of Miocene age which extend nearly or quite to the coast. Toward the west a strip of Miocene parallels the coast, lying south of the Upper Oligocene, from at least Ochlockonee River on the east to Apalachicola River on the west. In the southern portion of the State the surficial rocks are of late Tertiary age, mainly Pliocene, and consist of marls, gray, green and blue clays, soft limestones, shale beds, etc. In the central part of the northern portion of the peninsula great thicknesses of sands, mainly of Quaternary age, cover the older rocks, while along the northern boundary in the western part of the State occurs the southern edge of the mantle of yellow sands, etc., generally known as the Lafayette formation. Local deposits of coquina and other late Pliocene and Quaternary materials occur at a number of points near the coast. The structure of the peninsula is supposed to be anticlinal, and the occurrence of artesian water would appear to bear out the assumption. Except along the belt of Lower Oligocene limestones, where the land rises to an elevation of about 250 feet, and in a few of the sand hills the region is very low.

UNDERGROUND WATERS.

Highland area.—Along the northern border of the State and in the highlands extending southward along the center of the peninsula the elevation of the surface generally precludes flowing wells, the region being one of catchment rather than of discharge. There is, nevertheless, frequently a range of 75 feet or more in the local elevation of the surface in this region, and flowing wells are not uncommon. They depend, however, mainly on local conditions, artesian areas of any extent being absent. The waters seldom rise more than 10 feet above the surface even when the wells are located in the lowest depressions. Fairly good water may be obtained in most instances from drilled wells of moderate depth, but generally pumping has to be resorted to.

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[a] Compiled from data furnished by T. Wayland Vaughan.

Many of the depressions and channels of the highland area are marked by springs, some of which have been developed as resorts, while the waters of others are placed on the market for medicinal purposes. The springs are numerous and frequently of large size, giving rise, as in the case of Silver Springs, to streams navigable to their source. The waters, though hard, generally contain little sulphur and iron in solution.

West coast.—From the highland area the surface gradually slopes westward and southward to the coast. The area, as a whole, is very thinly settled, and relatively few wells have been drilled. In Hillsboro and Manatee counties, bordering upon Tampa Bay, and in the region extending into Polk County on the east, there is a considerable number of flowing wells. Flowing water is also found occasionally from Perry County westward to the western limits of the State, and it is probable that it could generally be obtained if the region was thoroughly tested. The land, however, is relatively low and ill adapted

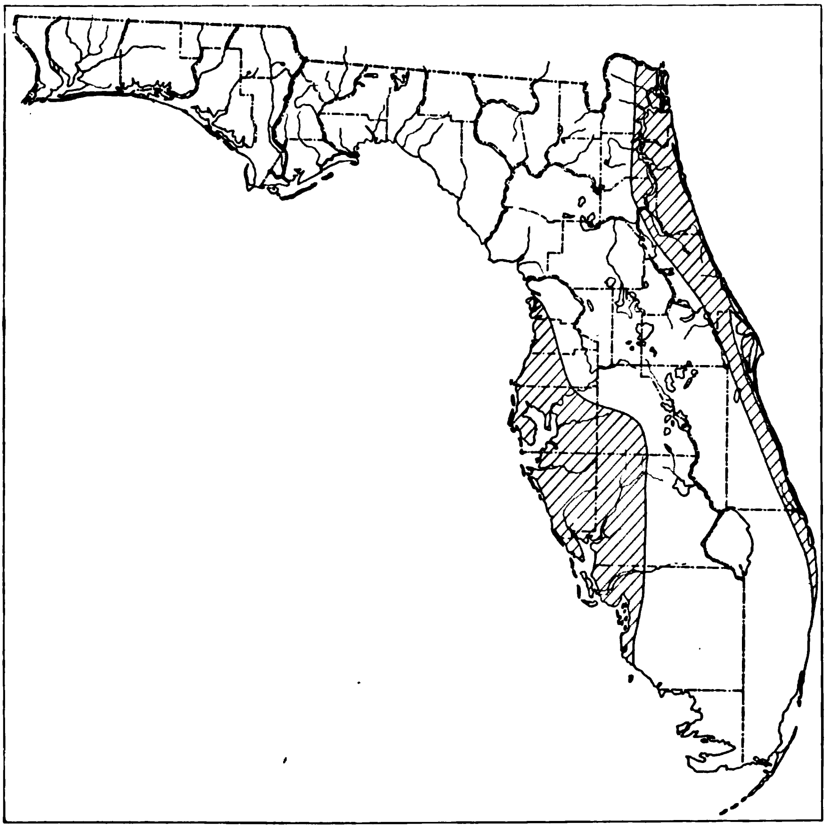

FIG. 22.—Principal artesian areas of Florida.

to settlement, and, moreover, contains numerous streams and springs, some of the latter forming streams of considerable size. The waters are generally charged with sulphur and are undesirable for many purposes.

East coast.—Most of the flowing wells of Florida are located along a strip from 20 to 40 miles in width, following the east coast from the northern boundary of the State southward to beyond Jupiter Point. The wells are most numerous along St. Johns River, which lies but a few feet above sea level and along the so-called Indian River between the main coast and the outlying reefs. The waters frequently rise 10 feet or more above sea level, and in some cases are reported to rise as high as 50 feet, indicating that the waters are derived from the highlands of the interior. This tends to bear out the assumption which has been made as to the arched structure of the rocks of the peninsula. Artesian wells are also found along the reefs and islands, but the shallow wells in such locations are brackish.

The waters from the flowing wells of this belt are extensively utilized for irrigation throughout the entire strip, both on the mainland and on the islands or keys. They are usually obtained at depths of from 200 to 400 feet, but occasionally wells are drilled to great depths. A few very deep wells failed to secure satisfactory supplies.

Springs of considerable volume, generally of sulphur water, are found along St. Johns River and on the coast.

Sand area.—Overlying a considerable area in the north-central part of the peninsula and to a lesser extent elsewhere are extensive deposits of sands of Quaternary age. Throughout this region the ordinary wells are mainly of the driven type. The depth is commonly from 10 to 100 feet, depending largely upon the elevation at which the well is started. The water, though hard, is generally not otherwise mineralized. In most instances it is reported to be satisfactory as regards health, but in some regions is not considered desirable for drinking purposes.

MINERAL SPRINGS.

In 1902 sales of mineral water were reported by the following springs:[a]

Hampton Spring, Rocky Creek, Taylor County.
Magnolia Springs, Magnolia Springs, Clay County.
Orange City Mineral Spring, Orange City, Volusia County.
Panacea Mineral Springs, Wakulla County.
White Sulphur Springs, White Springs, Hamilton County.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

The aggregate output is reported as 21,900 gallons, with a value of $8,277.

PRINCIPAL PUBLICATIONS.

Florida [well and spring records], by M. L. Fuller and B. M. Hall: Water-Supply and Irrig. Paper U. S. Geol. Survey, No. 102, 1904, pp. 238–275.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 85–87.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton, Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 21, 22.

ALABAMA.

By Eugene Allen Smith.

CRYSTALLINE SCHISTS.

Under this head are included both the igneous and the metamorphic sedimentary rocks, which from their close texture are not very permeable, and hence are poorly adapted to absorbing and storing underground waters, but which are very generally covered with a mantle of sandy clays, the result of weathering, which yield an ample supply of water to springs and shallow wells. While the conditions are as a rule unfavorable for obtaining artesian waters, there are two wells at Alexander which yield abundant water but do not overflow.

NONCRYSTALLINE FORMATIONS.

The noncrystalline formations are found in northeastern Alabama, and together with the crystalline schists cover two-fifths of the State. The constituent strata are sandstones, shales, and limestones, in many alternations and of various degrees of purity. Owing to folding and other movements these strata, with the exception of the Coal Measures, have a very decided dip, generally toward the southeast. They are not very porous; but the sandstones and conglomerates, when their pores are not too much clogged with argillaceous and calcareous material, are the most permeable.

Springs and shallow wells.—In all the Paleozoic series, and especially in the Carboniferous, the siliceous rocks above mentioned are the sources of springs and shallow wells which yield pure freestone water, holding in solution 12 grains or less of mineral matters, mainly the carbonates of sodium and calcium.

The shales are practically impervious, and where they prevail, as in the flatwoods of the Cambrian in the Coosa Valley above Gadsden, in the central belts of the anticlinal valleys, and in some parts of the coal fields, most of the surface springs go dry in summer and fall months. In some parts of the flatwoods the waters from the shales are charged with mineral salts, especially the sulphates of calcium and magnesium—containing as high as 127 grains to the gallon. From certain black bituminous shales of the Devonian containing disseminated pyrites are obtained strong sulphur waters that are known beyond the limits of the State. Such waters occur at Blount, Shelby, St. Clair, Talladega, and Alabama White Sulphur Springs.

The limestones are very generally fissured, channeled, and traversed by caves. Surface springs in limestone are therefore not important, except where they are formed by the emergence of underground streams. The "big springs," or limestone springs, thus originating characterize particularly the Knox dolomite of the Silurian and the lower Eocarboniferous formation. Some of the most noted of these big springs are at Tuscumbia, Huntsville, Montevallo, Talladega, and Jacksonville. The water is always charged with carbonate of lime.

Artesian systems.—The compactness and the steep dip of the rocks in the Paleozoic area do not offer favorable conditions for artesian wells, yet in a few cases deep borings have been successful. Thus at Anniston several wells in Cambrian strata have a depth of 250 to 500 feet, and the water rises nearly to the surface, but does not overflow. The supply is ample for the furnaces for which the wells were bored. On the southeastern slope of Red Mountain, near Gate City, there are four borings which reach depths of 25, 85, 103, and 344 feet. From two of these the water overflows; in the others, on slightly higher ground, it rises nearly to the surface.

In the Tennessee Valley, west of the meridian of Huntsville, the Eocarboniferous strata have a moderate southerly dip, and in most of the deep borings the water rises usually to within 30 feet of the surface, as near Sheffield and Russellville. A well near Decatur flows about 10 gallons per minute. This well was bored seventy-five years ago, and there has been no perceptible diminution during this time. In the Coal Measures of the Warrior basin the moderate and uniform dip of the strata is favorable to artesian wells, but the texture of the sandstones and other strata is not. Deep borings about Cullman and Tuscaloosa reach water which rises in the wells and can be pumped. At Jasper a deep well overflowed for some years after it was bored, but does not now.

Several borings in and near Tuscaloosa penetrate the Coal Measures and get a fairly good supply of water which rises in the wells but does not overflow. At the furnace of the Central Coal and Iron Company the well yields 500 gallons per minute. The water contains sodium chloride and the salts of magnesium and calcium.

COASTAL PLAIN.

In the Coastal Plain region, which includes about three-fifths of the State, the most important rocks are Cretaceous and Tertiary. The Cretaceous overlies the Paleozoic unconformably, and is in turn overlain by the Tertiary. The strata of both series are composed of alternating beds of sands, clays, and limestones, and have a slight Gulfward dip, which averages 40 feet to the mile. The surface of the country slopes in the same direction, but at a much less rapid rate, the elevation being about 600 feet above tide on the landward margin, and 200 feet in the two coast counties. Thus the lithologic and physical characters, the arrangement, and the gentle uniform southward slope of the component beds provide requisite conditions for artesian systems.

The Cretaceous and Tertiary rocks are covered unconformably by one, and in some places by two, formations of much later date—the Lafayette of Quaternary age and the Grand Gulf of late Tertiary or possibly Quaternary. The Lafayette is far more extensive than the Grand Gulf group, as it covers or has covered the entire Coastal Plain, and sometimes for miles overlaps the Paleozoic area. It was once probably continuous over this region, but it is now much dissected, and has been almost entirely removed on some areas, especially the chalk of the Cretaceous and the post-oak flatwoods of the Tertiary. The Grand Gulf group, on the other hand, is confined to the lower counties. In the western half of this region it overlaps the Miocene and the uppermost (St. Stephens) formation of the Eocene. Toward the east it covers parts of the Claiborne and even of the "Lignitic," and extends to the border of the Cretaceous.

The underground waters in the Coastal Plain are hence obtained from two sources—the artesian water from older rocks (Cretaceous and Tertiary) and the surface waters from the two surface mantles.

SPRINGS AND SHALLOW WELLS.

The Lafayette formation, consisting of red sandy loam overlying irregular beds of pebbles and averaging 20 to 25 feet in thickness, is most admirably adapted for absorbing and storing the rainfall. At its contact with the underlying older formations, pure freestone water occurs in springs, and may be made available everywhere by means of shallow wells. As the water percolates through sands and pebbles, it takes in solution a very small amount of mineral matter, generally less than 3 grains to the gallon, of which carbonate of lime is the chief ingredient. Wherever this mantle is found in patches of considerable extent, a never failing supply of the purest water may be counted on, and the country is traversed by perennial streams. However, it does not afford the requisite conditions for artesian systems, (1) because of the great irregularity in the stratification due to erosion and (2) because being a mantle it has a southward dip not greater than the slope of surface.

The Grand Gulf group resembles the Lafayette and underlies it directly wherever the two occur together, but is much more limited in distribution and more uniform and regular in stratification. It is therefore well adapted to serve as a water reservoir. Its waters, like those of the Lafayette, are in general exceptionally pure, though sometimes highly charged with dissolved salts, mainly carbonate of lime. In the best of them there are not more than 5 grains of mineral matter to the gallon. Freely flowing springs and perennial streams are not, however, so characteristic of this as of the Lafayette. Shallow ponds and depressions, where the moisture-loving plants constituting the "pine-barren" flora find their most favorable conditions of existence, are typical features of the Grand Gulf territory.

This formation is an admirable cover for artesian waters, because of the thick stratified clays in its upper members. Over a large portion of this region, notably about Brewton and Pollard and other localities in Escambia County, water of good quality flows from borings 100 to 400 feet deep. The water is obtained in part from the Grand Gulf group and in part from the underlying Tertiary beds.

Springs and shallow wells which obtain water from the older formations vary in character. If they have their origin in the great sand formations of the lowermost Cretaceous and of the Tertiary, they are numerous and reliable, though the water is sometimes unpalatable because of much dissolved mineral matter. In the limestone formations of the middle Cretaceous and upper Tertiary, surface waters are small in amount and unreliable, compelling recourse to artesian wells.

ARTESIAN WATER SYSTEMS.

The materials and the structure of the Coastal Plain formations are favorable to artesian wells, as the strata are composed of sands and clays in many alternations, and have a moderate and uniform dip southward.

The two lowermost divisions of the Cretaceous—the Tuscaloosa and the Eutaw—are prevailingly sands, alternating with sheets of clay. The Tuscaloosa is of fresh-water origin, while the Eutaw is a marine deposit. The water obtained from the Tuscaloosa beds holds usually less than 15 grains of dissolved solids to the gallon, mainly the carbonates of lime and sodium, with smaller proportions of sodium chloride and magnesium carbonate. The potable waters of the Eutaw sands, on the other hand, contain from 15 to 30 grains of solid matters per gallon, and the chloride and carbonate of sodium predominate, though occasionally the carbonate of lime is more abundant. Some of these waters are brines, holding as much as 260 grains of sodium chloride to the gallon.

In the area of the Selma chalk which immediately overlies the Eutaw surface waters are practically nonexistant except in wet weather, and recourse must be had to artesian wells or to cisterns sunk in the solid chalk rock. In this section most of the artesian wells obtain water from the Eutaw sands, which are 300 feet thick and in which four water horizons are recognized by well borers. The fourth or lowermost is generally the strongest and most reliable, yielding generally flowing water where the altitude is not over 215 feet above tide. In the eastern part of this area, in Russell County particularly, the water sometimes rises to altitudes of 300 feet.

Along the southern border of the chalk, as at Livingston and Linden, artesian borings must traverse the entire thickness of the limestone—1,000 feet—before reaching the water-bearing sands. Near the northern border, of course, the borings are much shallower, but here, in order to get a copious and reliable water supply, the borings must frequently go deep into the Tuscaloosa strata underlying the Eutaw. The upper members of the Tuscaloosa contain much purplish or reddish clay, generally referred to by the well borers as the "pink kaolin."

Hundreds of artesian wells supply the plantations of the prairie belt across the State and many cities, among which are Eutaw, Greensboro, Marion, Selma, Demopolis, Uniontown, Montgomery, and Union Springs.

The uppermost of the Cretaceous formations, the Ripley, is formed of calcareous sands which weather at surface into loose sands and are well adapted to collecting and storing surface waters. Springs and shallow wells in consequence generally afford an ample supply of water, which is usually limy. Below the belt of weathering, however, these beds do not appear to be very permeable, as is shown by the failure of most of the deep borings into them.

Near the base of the Tertiary, west of Alabama River, 200 feet of massive clays give rise to the post-oak flatwoods which are characterized by heavy cold soils, defective drainage, and deficiency of springs and surface waters generally during the dry seasons. The shallow wells sunk into these clays give a scanty and unreliable supply of water which is often unfit to drink because of excess of dissolved salts, especially magnesium sulphate, which is sometimes present to the amount of 100 to 210 grains per gallon. Waters of this character from wells near York and Curls, in Sumter County, are extensively used for medicinal purposes. The failure of the underlying Ripley sands to supply good artesian water is a great drawback to the flatwoods territory.

East of Alabama River the prevailing beds near the base of the Tertiary are limestones, which in Barbour County are of sufficient thickness to give rise to caverns, "Big Springs," and water conditions similar to those of other limestone areas.

In the "Lignitic" group of the Tertiary the alternations of sands and clays and their uniform moderate dip are favorable to artesian systems, and two artesian-water horizons are well known, the Nanafalia and the

Hatchetigbee. The same conditions prevail, also, in the lower part of the Claiborne division, but the St. Stephens limestone at the top of the Eocene is, of course, not to be counted among the good water bearers. In the Tertiary area of Alabama the artesian wells are not so common as in Mississippi, but there are enough of them to prove that artesian water of good quality may be had in abundance. The abundance of good water furnished by the Lafayette formation has rendered the sinking of artesian wells for individual use unnecessary, but many towns in the lower counties have recourse to deep borings for their supplies, and the number of artesian wells increases yearly.

The late Tertiary (Miocene) formations underlying Mobile and Baldwin counties, have likewise all the requisites of artesian systems. In and near the city of Mobile several wells, 700 to 1,550 feet deep, obtain abundant water, which is sometimes potable and sometimes excessively salty. On the coast at Bayou La Batre an artesian well supplies the canning factory. It is 580 feet deep, and the water rises 15 feet above the surface. The water holds only 14.4 grains of dissolved mineral salts per gallon, chiefly the chloride and carbonate of sodium.

BRINE AND GAS WELLS.

This record would be incomplete without some reference to the brine and gas wells of Washington and Clarke counties, which occur along the southern border of the Hatchetigbee anticline and its southeastward prolongation. Most of these borings are located in the palmetto flats of small creeks, near their mouths, and at the base of hills capped with the St. Stephens limestone. Beginning in Claiborne strata at the surface they penetrate 100 to 400 feet into the underlying Hatchetigbee sands. The water rises to the surface in all cases, and at many points there are natural brine oozes, which may be converted into reservoirs of salt water by inclosing an area of 15 or 20 feet diameter by a palisade of heavy timbers and digging out the interior. During the civil war the brine from these wells and reservoirs was extensively used in the manufacture of salt. In most cases natural gas in considerable quantity accompanies the salt water, and frequently the weak brines are strongly impregnated with sulphuretted hydrogen gas, producing the most palatable sulphur waters in the State.

Of this character are the waters of the well at Jackson, in Clarke County, and at several of the salt works. Natural gas is also associated with the salt waters from other horizons. The deep well at Cullom Springs, Choctaw County, yields much gas along with salt water, and the Bascomb well near Mobile throws up a foaming jet of mingled salt and gas, which on ignition burns with a flame several feet in height.

MINERAL SPRINGS.

Of the many large springs only eight were reported in 1902 as utilizing their water for shipment. These springs are as follows:

Bailey Springs, Bailey Springs, Lauderdale County.
Cherokee Spring, Citronelle, Mobile County.
Healing Springs, Healing Springs, Washington County.
Ingram Lithia Springs, Calhoun County.
MacGregor Spring, Spring Hill, Mobile County.
Talladega Springs, Talladega County.
Wilkinson's Matchless Mineral Wells, Greenville, Butler County.
York Aperient Well, York, Sumter County.

The total output is placed at 68,050 gallons, with a value of $28,109.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 88–94.
Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 10–11.
Alabama [well records], by E. A. Smith: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, pp. 276–331.

MISSISSIPPI.

By L. C. Johnson.

GEOLOGY.

The geologic structure of Mississippi is very simple, but the details of the distribution of various formations are hard to make out owing to the extent to which the underlying rocks are concealed by more recent deposits, such as the river alluvium, loess, and Orange sand or Lafayette formation.

The oldest rocks in the State are comprised in a series of limestones of Mississippian ("Lower Carboniferous") age, which outcrop in northeastern Mississippi and cover much of Tishomingo County, and a small portion of Itawamba County. South, southwest, and west of this older rock mass outcrop successive parallel bands of later rocks, which dip away from the Carboniferous mass in a direction which varies from south to west. Along the Alabama State line, for example, the dip is practically due south; along the Tennessee line it is almost due west, while in intervening sections it is southwest. The amount is slight, averaging probably about 25 to 35 feet to the mile. Southward or westward from Tishomingo County newer and newer series of rocks outcrop until recent alluvial deposits are found along the Gulf and Mississippi River.

The distribution of the more important of the geologic formations are shown in the accompanying sketch map (fig. 23).

MISSISSIPPIAN ("LOWER CARBONIFEROUS") ROCKS.

The Mississippian rocks occupy an area covering portions of Tishomingo and Itawamba counties. They consist largely of limestones. They abound in springs, which are so numerous and accessible that there has been little demand for deep borings, though open wells with a depth of 100 feet and yielding good water are not uncommon. A few of the well waters are mineralized. Some of the springs issue from the Mississippian rocks and some from the Cretaceous sands which thinly cover the harder rocks along the borders of the area.

Two important springs occur in the area. The first, known as Bay Spring, is located near the falls of Mackay Creek, and may have its source within fissures of the limestone. The waters are of normal purity. The second spring, the Iuka, is a medicinal spring containing considerable amounts of sulphur, iron, sodium, and calcium. It is located in the city of the same name and has been developed as a health and pleasure resort.

CRETACEOUS DEPOSITS.

Southwest of the Mississippian area are the Cretaceous formations. These occupy a belt outcropping around the area of Mississippian rocks. In general, water may be obtained in this section by wells at a depth of from 200 to 1,500 feet, the depth increasing with the distance from the contact with the Mississippian. Few of the wells flow, but the water generally rises to within easy pumping distance of the surface. In quality, the water is usually more or less alkaline, but in a few wells it is pure and soft.

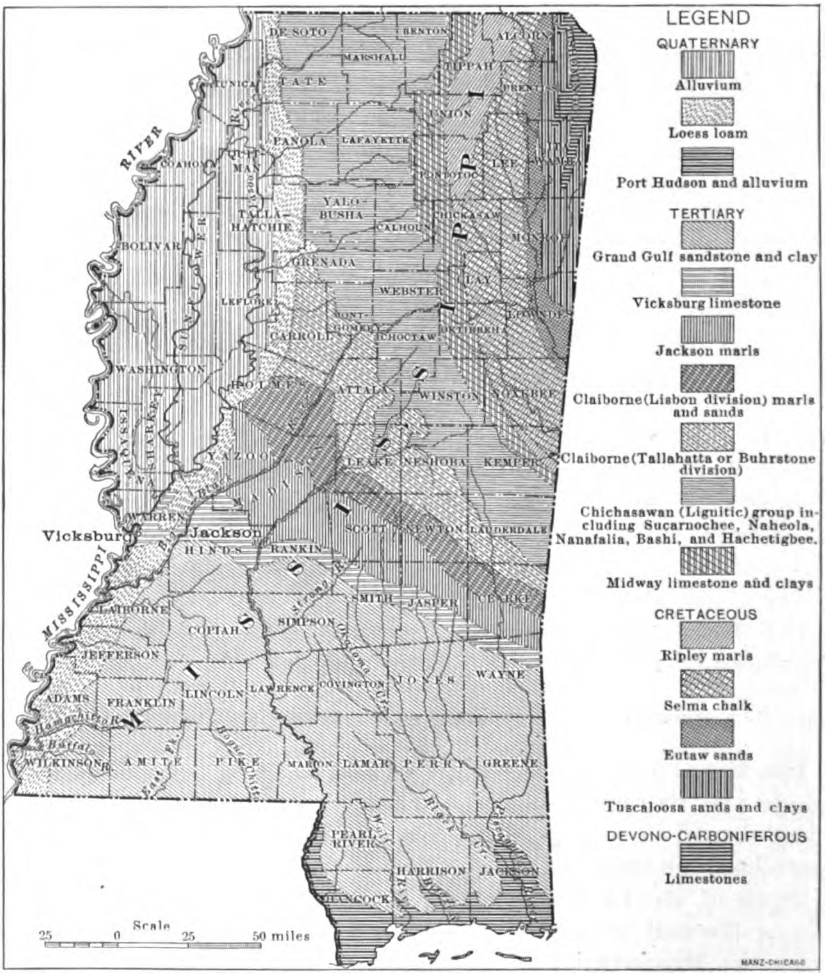

FIG. 23.—Geologic sketch map of Mississippi.

Tuscaloosa formation.—This oldest Cretaceous formation, which consists largely of variable beds of sands and clays, is separated into two parts by a persistent bed of purplish clay. The upper portion generally yields only small amounts of unsatisfactory water, but the lower half and the sandy bed at the top of the upper half yield copious supplies of good water. Wells drawing their supplies from this formation are located at Columbus, Lowndes County, at Gattman, Aberdeen, and Amory, Monroe County, and elsewhere. Springs are not uncommon where streams have cut into the deposits. Kolola Spring on Buttahatchee River, in Lowndes County, has considerable reputation because of the medicinal properties of its water, which carries sodium, potassium, magnesium, calcium, and iron, especially the latter.

Eutaw beds.—The name Eutaw has been applied to the sandy beds between the Tuscaloosa formation and the overlying Selma chalk. In Alabama the Eutaw beds usually yield saline waters, but in Mississippi they are not water bearing, the wells generally passing through them into the underlying Tuscaloosa formation.

Selma chalk or Rotten limestone.—In Mississippi this formation is not a water-bearer, but throughout the prairie regions of the northeastern part of the State it serves as a cap rock to the water-bearing bed at the top of the Tuscaloosa formation. There are more than a hundred deep wells each in Noxubee, Lowndes, Clay, Monroe, and Lee counties, and there is a large number of wells in Oktibbeha, Chickasaw, Prentiss, and Union counties. In the western parts of these counties there are fewer wells than in the eastern, not because of the impossibility of obtaining water, but because the wells must be deeper and are therefore more costly.

The regularity of the water-bearing beds as shown by the wells indicates there has been no material disturbance or dislocation of the deposits beyond a simple tilting westward from the contact of the Rotten limestone and Tuscaloosa beds at the rate of 25 feet to the mile.

Ripley beds.—The Ripley beds in Mississippi consist of a series of sands, marls, and limestones outcropping west and southwest of the Selma chalk or Rotten limestone. Until recently no water supplies of importance had been obtained from these beds, but abundant water has lately been found in a number of wells at Ecru, in Pontotoc County. The wells appear to be located in a local syncline or trough and have an average depth of about 200 feet. Most of them flow at the surface.

Springs are not abundant in the Ripley beds, but they frequently occur along its contact with the overlying Lafayette sands and gravel. The large Blue Mountain Spring is an example of this type. It carries a small amount of calcium and magnesium carbonates, derived, it is supposed, from the underlying marls of the Ripley beds.

TERTIARY DEPOSITS.

Westward from the limits of the Selma chalk or Rotten limestone to the delta district, and southward to the southern portion of the State, lies the broad belt of Tertiary deposits, which have been divided into a considerable number of formations, each of which is considered below.

Midway.—The Midway beds consist of limestones overlying the Ripley sands, marls, etc. The thickness is slight and they do not carry any considerable amount of water.

"*Lignitic*" *group.*—One of the most important divisions of the Tertiary is the "Lignitic" group, which is further subdivided in Alabama into (1) the Sucarnochee, consisting of black clays, (2) the Naheola, (3) the Nanafalia, (4) the Bashi, and (5) the Hatchetigbee formations. The last four consist largely of gray lignitic clays, with occasional marl beds and some water-bearing sand.

The general structure of the region underlain by the Lignitic group is favorable to obtaining water, both by wells and springs. The surface elevation, however, is so nearly uniform that even deep borings seldom produce flowing wells. Where the streams have cut into the deposits numerous springs issue from the banks, except in the case of the Sucarnochee formation.

The Sucarnochee formation is a deep black clay, very impervious to water. Springs frequently issue from the more porous beds overlying it, but it is itself practically destitute of water.

The Naheola formation contains a few sandy beds yielding small flows of water. Wells at Lauderdale penetrate these beds at depths of from 100 to 200 feet, and obtain weak flows rising 2 or 3 feet above the surface. Similar wells have been obtained in this formation at scattering points elsewhere. Some of the largest springs of Mississippi appear at the contact of the Naheola with the underlying clays of the Sucarnochee formation. Like the Naheola these formations consist of grayish lignitic clays with occasional marl and sand beds. They are not important water horizons. At Meridian borings penetrated the "Lignitic" strata from the Hatchetigbee down to the Sucarnochee, but the water only rose to within 20 feet of the surface.

There are a number of springs from the Nanafalia formation, one of which, the Lauderdale, is of considerable importance. The waters, which carry considerable sulphur, issue from lignitic beds on a branch of the Sucarnochee River, near Lauderdale. A health resort has been developed at the spring.

The Hatchetigbee formation is similar to the preceding Lignitic formations, but carries thicker beds of sand, and is therefore a more important water-bearing formation. It underlies a considerable portion of the delta deposits, and is thought to be the source of water of the wells drilled through the deposits of the delta at Memphis, Tenn., Tunica, Coahoma, Quitman, Tallahatchie, Leflore, Sunflower, Bolivar, and other places. The depth constantly increases toward the south and west from 850 to 1,300 feet.

The most important spring in the Hatchetigbee deposits is the Arundel Lithia Spring. The water issues from the Hatchetigbee sands, where Oktibbee River and Sowoshee Creek have removed the Buhrstone and cut away the sands down to the stiff clay beneath. Considerable amounts of the water are sold. The whole of the adjoining region is marked by numerous springs, but in general none of them have been improved nor the water marketed.

Tallahatta formation (*buhrstone*).—The Tallahatta formation consists essentially of a series of hard sandy beds, more or less porous in places, comprising the lower portion of the Claiborne group. It contains little water in itself, but forms an impervious cap rock to the water-bearing sands of the underlying Hatchetigbee. By its resistance to erosion the Tallahatta has given rise to an elevated ridge which is of much assistance in the location of water-bearing beds. Water which rises to a greater or less distance is almost always found beneath it, the local topography determining whether the well will flow or not. This horizon supplies the wells at Stonewall (300 feet), Quitman (500 feet), Enterprise (200 feet), all in Clarke County; at Grahams Switch (90 feet), and Meehan Junction, in Lauderdale County, and at Chunky and Hickory (500 feet), in Newton County. It is also probable that the artesian flows at West, Pickens, Durant, Tchula, and Lexington, in Holmes County, are from the same source. To the above list may possibly be added the deep wells at Jackson, Hinds County (964 feet), and at Canton, Madison County (1,020 feet), both of which, however, were bored through the Jackson and Claiborne marls before penetrating the Hatchetigbee beneath the buhrstone.

Lisbon formation (*calcareous Claiborne*).—This formation consists of marls and green sand, and has a total thickness of about 300 feet. It contains several minor beds of ferruginous water-bearing sands, but none of them are as persistent as the Hatchetigbee. One of these beds is encountered at 300 feet at Shubuta, and at 500 feet at Waynesboro. The water from these wells is colored by the iron, and is also highly alkaline.

A local sand bed of the Lisbon formation yields colorless, but chalybeate water in the double wells at Shubuta, and in the wells at De Soto and Pachuta. The water in the last well only comes within 20 feet of the surface.

Springs are by no means rare in the Lisbon area, but they are generally supposed to come from the overlying Lafayette sand. A few, however, are probably of deeper-seated origin. The Archusa Spring, near Quitman, Clarke County, is derived from these beds.

The water is sulphurous and alkaline. The Pierce Spring, near the banks of Bucatanna Creek, in eastern Clarke County, is also strongly mineralized. The Robinson Spring, in Madison County, which has been developed as a health resort, yields water similar to that of the springs in Clarke County.

Jackson and Vicksburg formations.—These two formations, which may be grouped together, consist of marls, clays, and limestone, the latter predominating in the upper or Vicksburg division. There are few sandy beds and artesian waters are generally lacking. The flowing wells located in the area of outcrop obtain water from the ferruginous sands of the Lisbon formation at Shubuta and Waynesboro, and from the Hatchetigbee sands at Jackson (964 feet) and Canton (1,020 feet). An important mineral well, known as the Cooper well, is located 3 miles east of Raymond. It is 90 feet deep, and at this point has been developed the most important health resort in the State. The water contains iron, magnesia, soda, and sulphur. Another well-known mineral well, near Hazlehurst, Copiah County, obtains water from this formation. The water is impregnated with sodium and magnesium chlorides and calcium sulphates. It occurs at a depth of 63 feet, probably in a lignite bed. A third mineral well of importance is the Godbold, 1¼ miles from Summit, Pike County.

Springs in the area of outcrop of this formation are really from the sands and gravels of the overlying Lafayette. The best known of these break out along Paulding Ridge, in Jasper County. Those issuing on the north side generally yield pure, soft water; those on the south are usually mineralized. The Phalti Spring (sec. 8, 2 N., R. 13 E.); Bay Spring, at Bayspring post-office; Donald's mineral spring, near Weems; and Vosburg and Stafford springs, in the same vicinity, are among the most important.

Grand Gulf group.—The Grand Gulf is by far the most extensive formation in the State, and consists of a variable series of sandstones, sands, and lignitic clays. Practically every sand bed, of which there are a great number, is water bearing, and supplies are obtained by dug, bored, and drilled wells. Where stream erosion has cut into the beds to any considerable distance springs occur. At Hattiesburg, Laurel, Brookhaven, and Natchez water is obtained at depths of from 200 to 400 feet, but only at Hattiesburg does it rise above the surface. There are considerable evidences of undulations of the beds in the Grand Gulf area, the flowing water at Hattiesburg being referred to a shallow synclinal trough at that point.

Among the springs and mineral wells may be mentioned the Mississippi Springs in Hinds County (sec. 2, T. 5 N., R. 4 E.); the Mammoth Mineral Springs, Perry County (secs. 24 and 25, T. 5 N., R. 14 W.); and Rawls Spring, 2 miles farther west. The Mammoth Spring, 6 miles northwest of Hattiesburg, is a large spring issuing from lignitic clays. Both the Mammoth and Rawls springs are noted for the medicinal value of their waters.

QUATERNARY.

Lafayette sands and gravels.—The Lafayette formation is poorly defined, but may be considered as made up of a series of yellowish or orange sands and gravels occurring as a mantle over the outcropping edges of the Grand Gulf and other formations. Because of its sandy and gravelly character it contains, especially at the base, a large amount of water, which is usually pure and soft, and which is obtained by shallow wells.

Loess and loam.—The loess consists of fine fossiliferous yellowish silts, while the loam consists of browner silts, possibly produced by the weathering of the loess. The deposits occur over the Yazoo delta region in the northwestern part of the State. Only very small amounts of water can be obtained in the loess or loam, practically all of the wells passing through it into the underlying Lafayette or still older formations.

Pontchartrain clay and Biloxi sand.—The Pontchartrain clay is a greenish clay occurring in a narrow belt in the extreme southern part of the State, and separated from the coast by a very narrow strip of sandy beds, known as Biloxi sands. Shallow wells in these two formations everywhere obtain abundant water at shallow depths, although the quality is not always satisfactory. To obtain flowing water the wells must extend to the Grand Gulf formation. Water is found at depths of approximately 400, 600, 700, 850, and 900 feet.

The buckshot lands of the delta have sometimes been referred to the Port Hudson group, which includes the two formations under discussion. The water is generally fairly abundant and soft, but has not been found to be wholesome for drinking. In the northern part of the delta area water can be obtained from deep wells reaching to the Tertiary beds.

Alluvium.—Under alluvium are included the surface materials of the Mississippi delta region and the deposits in the lower portions of the courses of other large streams. The waters, though soft, are not regarded as wholesome.

MINERAL WATERS.

In 1902 shipments of mineral water were reported from the following seven springs:

Arundel Lithia Springs, near Meridian, Lauderdale County.
Browns Wells, Browns Wells, Copiah County.
Castalian Springs, near Durant, Holmes County.
Godbold Mineral Well, near Summit, Pike County.
Lowes Wells, Hazlehurst, Copiah County.
Robinson Mineral Springs, Robinson Springs, Madison County.
Stafford Mineral Springs, near Vosburg, Jasper County.

The aggregate amount sold is reported as 459,485 gallons, valued at $77,868.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 95–97.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 57.

Mississippi [well records], by L. C. Johnson and E. C. Eckel: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, pp. 332–357.

LOUISIANA AND SOUTHERN ARKANSAS.[a]

By A. C. VEATCH.

GENERAL GEOLOGY.

Louisiana and Arkansas, south of Arkansas River and the mountains, have the same general structure as the great American Coastal Plain, of which they form a part. The land is highest toward the old plateau and mountain region to the northwest. The beds are for the most part unconsolidated, succeed one another in more or less regular succession, range in age from Cretaceous to Recent, and in general have a dip coastward that is greater than the slope of the surface. This relation of dip to surface slope supplies conditions which are favorable for artesian water, therefore flowing wells should be expected in many parts of the Coastal Plain. In some cases the leakage and resistance of the sands so reduces the pressure that the water will not flow, although the altitude of the well mouth is less than that of the point where the sands come to the surface and where the water enters; in others, erosion has so changed the surface of the plain that the well mouth, though south of the outcrop of the water-bearing bed, is higher, and the water, therefore, will not flow. In Louisiana and southern Arkansas the older beds slope toward the Mississippi Valley as well as toward the coast. Some of these older beds are very much disturbed and form peculiar, sharp domes, and as they often contain salt water, and are frequently broken by the folding, the salt water is free to pass into the sands of the surrounding younger formations. While these domes disturb the conditions in certain tracts, there are still larger areas in which wells have found good water. A study of these well records and of the general structure of the country shows that the following principal water horizons are present: Bingen sand, Nacatoch sand, Sabine sands, Catahoula sandstone, Pliocene and Quaternary sands and gravels.

The relation of these beds to one another is shown in figs. 24 and 25, and their geologic age and relation to adjacent beds are shown in the table following.

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[a] A preliminary statement. A detailed report on this area, embodying records of all important wells and well prospects for each county is now in preparation and will be ready for distribution late in 1905.

Water-bearing value of geologic formations of Louisiana and southern Arkansas.

Period or formation.	Maximum thickness.	Water-bearing value.
Quaternary	[a] 2,000	Contains gravel and sand beds, which furnish the main supply of water in southern Louisiana.
Pliocene		As surficial deposits on the uplands and in the valleys, supply much of the shallow well water of this region.
Miocene	(?)	No surface outcrop, and hence probably of no importance as a water horizon.
Oligocene:		
Fleming	± 200	Clays and marly clays; no water-bearing value.
Catahoula	[b] 1,000	The coarser sandstone layers of this formation furnish excellent water. Three or four horizons have been developed.
Vicksburg	50-100	Exposed in only one part of the area and of no importance from a water standpoint.
Eocene:		
Jackson	500	Clays and clay marls with occasional sand beds; water generally hard and seldom developed.
Cockfield	500	The sandy beds occurring near the base of the formation are second in importance only to the Sabine.
Claiborne	500	Clays and clay marls containing sand beds of little importance as water horizons.
Sabine [c]	1,000	The sands of this formation are the important water horizons of the greater part of northern Louisiana and adjacent parts of Arkansas.
Midway	(?)	Exposed only to a limited extent in one part of the area, and unimportant as a water-bearer.
Upper Cretaceous:		
Arkadelphia	[d] 600	Clay beds, which serve to retain water in Washington sands.
Nacatoch	150-200	One of the most extensively developed water sands of this region. Very good water near the outcrop, but brackish in the embed.
Marlbrook	400	Clays, clay marls, and chalk; serve to retain water in the Bingen sands.
Annona	+100	
Brownstown	300	
Bingen	+500	Persistent sandy bed, furnishing water over a wide area.
Lower Cretaceous	[e] 550	Not known to contain any important water-bearing layers in this region, though the great development in eastern Texas would lead us to expect some development here.
Paleozoic	(?)	Hard rock layer very much disturbed. Contains water, but its occurrence can not be predicted until the geology of the region is minutely understood. In general, not very good field for water wells.

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[a] Harris, G. D., Organic remains from the deep well at Galveston: Fourth Ann. Rept. Geol. Survey Texas, 1893, p. 118. Harris, G. D., Report of Louisiana Geol. Survey for 1902, p. 32.

[b] Based on dip calculations on the Sabine River, and on the thickness of these beds in the Alexandria, La., wells, 800+ feet.

[c] Name adopted to supplant Lignitic; taken from typical fosiliferous development of the formation on the Sabine River, in Sabine County, Tex., and Sabine Parish, La.

[d] Based on wells south of Hope, at Arkadelphia and Shreveport; may be in part Midway.

[e] Hill, R. T., The Mesozoic geology of southern Arkansas: Ann. Rept. Arkansas Geol. Survey for 1888, p. 188.

WATER HORIZONS.

Lower Cretaceous.—The lower Cretaceous occupies the wedge-shaped territory between the Paleozoic rocks and the Bingen sands (fig. 24). All deep wells in this region have thus far failed to yield water, though the extensive development of water sands in this group in Texas leads to the belief that further attempts, especially in the western part of the State, will not be fruitless. The best water-bearing sands are to be expected near the base of the Cretaceous or just above bed rock. The depths at which bed rock will be encountered may be roughly found by multiplying the distance in miles between the Paleozoic out-

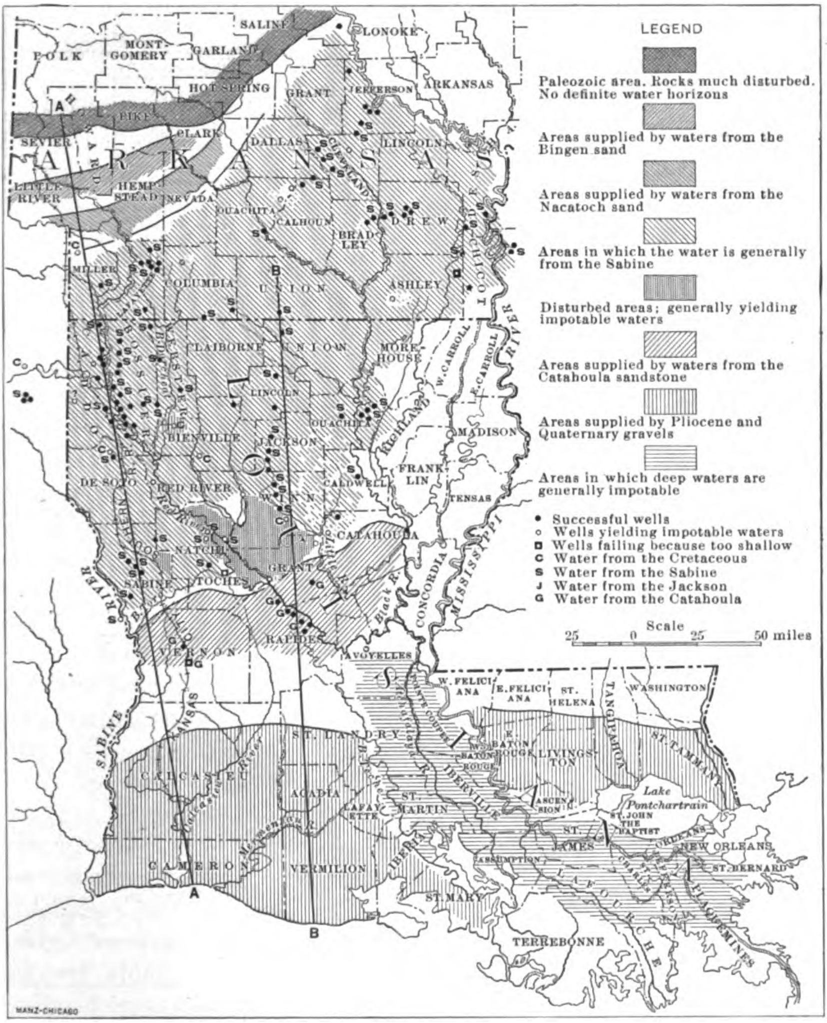
LEGEND
Paleozoic area. Rocks much disturbed. No definite water horizons
Areas supplied by waters from the Bingen sand
Areas supplied by waters from the Nacatoch sand
Areas in which the water is generally from the Sabine
Disturbed areas; generally yielding impotable waters
Areas supplied by waters from the Catahoula sandstone
Areas supplied by Pliocene and Quaternary gravels
Areas in which deep waters are generally impotable
● Successful wells
○ Wells yielding impotable waters
□ Wells failing because too shallow
C Water from the Cretaceous
S Water from the Sabine
J Water from the Jackson
G Water from the Catahoula
Scale
25 0 25 50 miles
A
B
MANZ-CHICAGO

FIG. 24.—Deep-water prospects in Louisiana and southern Arkansas. A–A, line of section shown in fig. 26; B–B, line of section shown in fig. 27.

crop and the point where the well is to be sunk by the average rate of slope of the bed-rock surface, 100 to 125 feet per mile.

Bingen sand.[a]—The Bingen sand comes to the surface along and south of the line shown in figs. 24 and 25. Along this line shallow wells are, therefore, the rule, but as the sand dips at a rate of 50 to 75 feet per

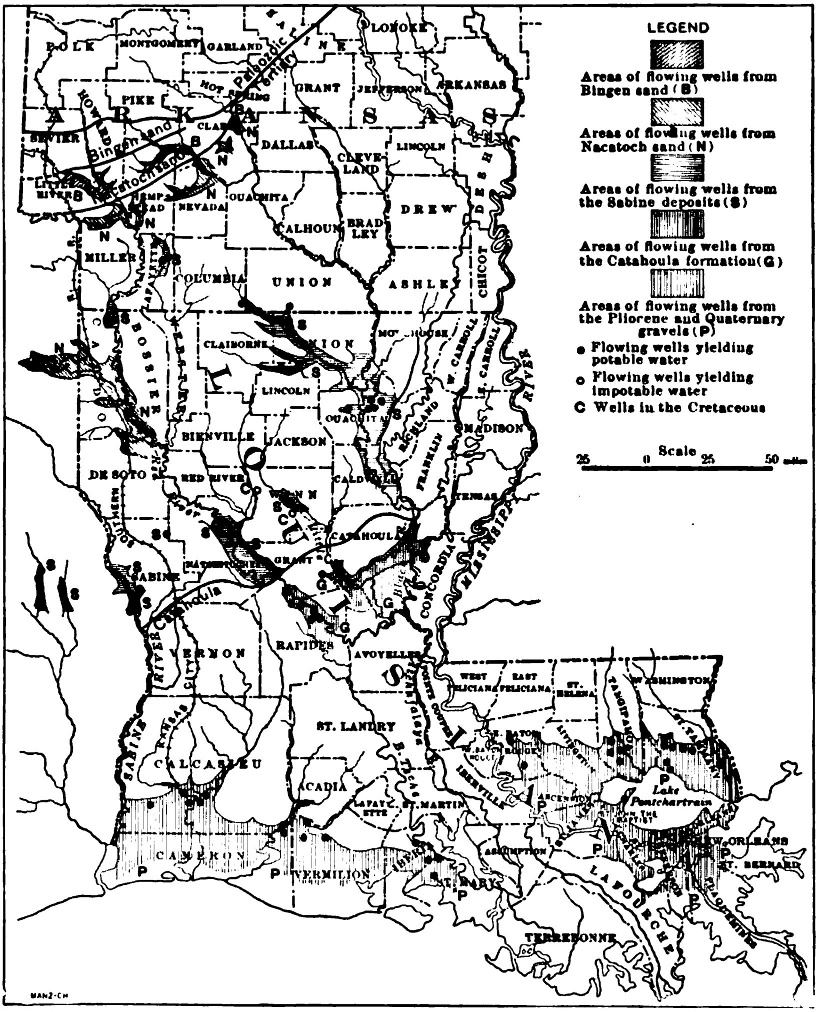

FIG. 25.—Artesian areas in Louisiana and southern Arkansas.

mile in a southeasterly direction, the wells get deeper to the south, and reach an extreme depth of 784 feet near Columbus, a little north of the outcrop of the Nacatoch sand. Some failures have been reported in the lower part of this territory, notably at Columbus and

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[a] Name used by Hill for beds which he doubtfully referred to the Eocene. These, with the exception of a single Nacatoch outcrop which was incorrectly included in this series, are now known to pass beneath the Brownstown and to represent the littoral beds of the basal upper Cretaceous.

Washington, but they were due to the fact that the wells were abandoned before the required depth had been reached. The greatest development has naturally been in the region where flowing water can be obtained (fig. 25). The maximum depth to which wells will be driven in this region will probably not exceed 900 feet, as before this depth will become necessary the Nacatoch sands will appear on the surface, making good shallow wells possible.

The water is very soft and somewhat alkaline, except in wells which do not flow and have only been partially cased, and in which the water therefore stands in contact with the overlying calcareous clays. Hard water has been found in a few wells, as at Hudson and near Burtsell, but in these it seems to occur in the calcareous beds which overlie the Bingen sands, and the indications are that if the wells had been deepened 200 or 300 feet they would have reached the Bingen and obtained soft water.

Nacatoch sand[a].—This sand, like the Bingen, is of very great value to a large section in southern Arkansas, where it is practically the only available source of well water. In areas underlain by the Bingen and Nacatoch sands the surface formations are rich, calcareous clays, with here and there thin coatings of younger gravel, and the surface water is generally hard and very unsatisfactory. Persistent water-bearing horizons, which are so well understood that the depth to water can be predicted at any point and which will furnish soft artesian water over wide areas, can not fail to have a great effect on the development and land values of the regions which they underlie.

The Nacatoch sand has been extensively developed along the line of the Iron Mountain Railroad from west of Red River almost to Arkadelphia (fig. 24). It dips southeastward at a rate of from 50 to 100 feet per mile until it reaches a point about 800 feet below sea level, when it abruptly becomes horizontal and continues so to a point somewhat south of Shreveport, where it again slopes normally

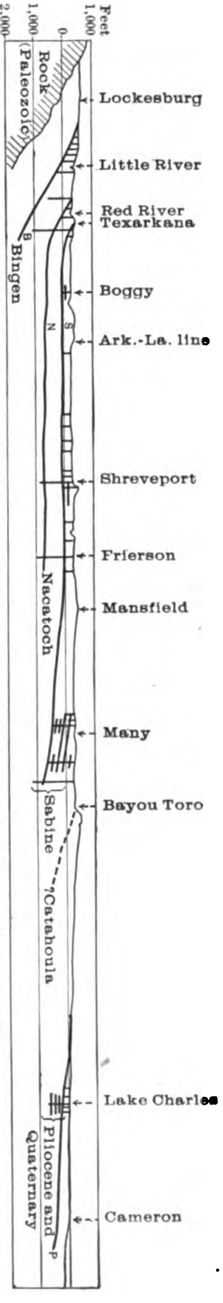

FIG. 26.—Section from Locksburg, Ark., to Cameron, La., showing principal water-bearing beds.

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[a] Name taken from typical exposure at Nacatoch Bluff on Little Missouri River in Clark County. This formation includes the sand beds between the Marlbrook and Arkadelphia which Hill included in his Washington or High Bluff greensands (Ann. Rept. Arkansas Geol. Survey for 1888, vol. 2, 1888, pp. 72-75, 188).

coastward (fig. 26). This extensive horizontal development would make this sand of great value over wide areas were it not for the fact that south of a line which runs irregularly from 3 to 15 miles from the outcrop the water is salty. Seemingly that portion of the sand near the outcrop has been thoroughly washed by percolating waters, while that less favorably situated is in its original salty condition, and the saltiness may even have been increased by matter washed down from the upper layers. Developments at Texarkana, Jefferson, Shreveport, and Frierson have yielded impotable water, which at the last three places is artesian, indicating an artesian basin covering a considerable part of the Red River Valley (fig. 25). The brine which occurs in some of the Cretaceous uplifts in northern Louisiana is likewise from this horizon. In general, it is felt that that portion of the sand which lies south of the area shown in fig. 24 will not furnish potable water.

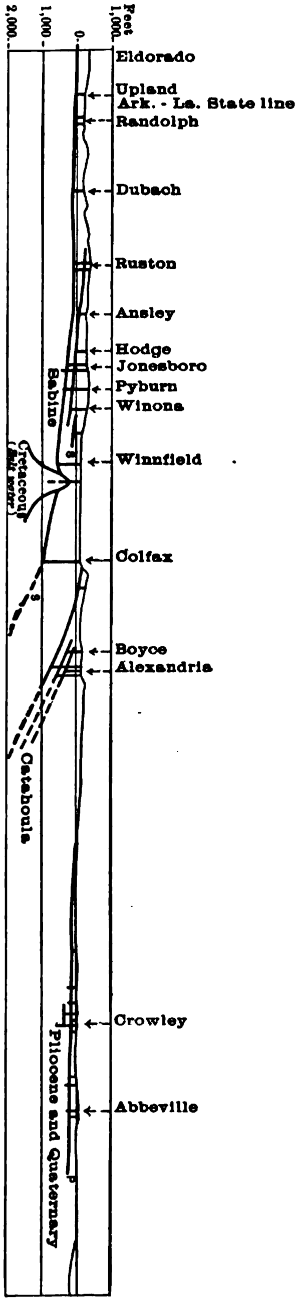

FIG. 27.—Section from Eldorado, Ark., to Abbeville, La., showing principal water-bearing beds.

Sabine group.—Under this head is classed not a single well-defined horizon like the Nacatoch, or Bingen, or other Cretaceous beds, but a number of somewhat irregular water sands occurring throughout a formation which, in the western part of this area attains a thickness of perhaps 1,000 feet. The lowest of these sands occurs about 700 feet above the Nacatoch, and like it, is very nearly horizontal over a considerable area (figs. 26, 27). Eastward and southward this bed dips gently toward the Mississippi Valley and the coast.

Other sand beds occur in the formation above this one, at varying distances from each other, and of varying thickness. Nine have been developed at Plymouth, La., and six at Ruston. These beds thin and thicken very rapidly, so that in one well a sand may be developed which in a nearby well is too thin to give results. Wells, then, show considerable irregularity in depth, some wells developing one bed and some another; but in general the wells are deeper to the south and toward the Mississippi Valley, as in each case the dip carries the sands beneath younger beds, and it becomes necessary to pass through a certain thickness of overlying deposits even to reach the topmost water sands of this series.

The failures in the southern part of the territory, near Natchitoches and Luella, La., are due to the occurrence of salt water, which is doubtless traceable, in part, to the neighboring uplifts of the older Cretaceous beds. These beds generally carry artesian brines, and as they are often broken the brine leaks into the surrounding Sabine sands. In the region of these domes it is often possible to predict the position of a sand, but it is quite impossible to indicate the kind of water it will contain. It is believed that the sands which furnish brine at Luella and Natchitoches are a continuation of the sands which yield good water about Shreveport.

Cockfield beds.—Overlying the Sabine are the fossiliferous Claiborne beds, which have little water-bearing value. Above the fossiliferous Claiborne are the Cockfield beds, which contain near their base an important water-bearing horizon. In central Louisiana the deeper wells which penetrate this horizon, as those at Leland, Rochelle, Olla, Tullos, and Colfax, obtain impotable water, though an exception is to be noted in the case of the deep well at Robinsons Ferry on Sabine River, in which a soft, pleasant-tasting water is reported at a depth of 1,010 to 1,030 feet. Near the outcrop successful wells have been finished at Clarks in Catahoula Parish, and at Weavers Spur in Natchitoches Parish.

In southeastern Arkansas and northwestern Mississippi this horizon is very extensively developed and furnishes good supplies of soft alkaline water at depths of 400 to 500 feet below sea level.[a] Between it and the base of the Jackson in this region a number of water sands have been developed in different wells, but they show little regularity and the better wells have, almost without exception, been finished in the main horizon.

The outcrops of the Cockfield sands in Arkansas and Louisiana are all relatively low, and the water will generally not rise much above 100 feet above sea level. Flowing wells will be obtained along the main stream channels in central Louisiana. In Arkansas and northwestern Mississippi the artesian area is near the eastern side of the flood plain where a relatively higher head is developed, because of the greater average height of the Mississippi hill lands. Water will rise very near the surface over all the flood plain, but in Arkansas it is regarded as quite impossible that flowing wells will be obtained.

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[a] The wells in Chicot, Drew, Bradley, Cleveland, and Jefferson counties, except the deep ones at Pine Bluff, which are incorrectly marked S in fig. 23, should be credited to this horizon.

Jackson beds.—Beds of this age generally furnish hard water, and are therefore not extensively developed.

Catahoula beds.[a]—The sands and sandstone of this formation are good water carriers, and have yielded excellent results in central Louisiana, where they furnish flowing wells at Zimmerman, Boyce, Alexandria, Pollock, and Harrisonburg. Several horizons have been developed which furnish soft water of a very good quality, and it is probable that over a considerable area along Ouachita and Black rivers and about Catahoula Lake and Little River (fig. 25) flowing water is to be expected from these sands. Flowing wells will doubtless be obtained in Sabine River Valley below the outcrop of the Catahoula, as indicated by the water obtained from these beds on the Angelina near Rockland, Tex.; but in the high hill region about Leesville the wells will probably be very deep, and the water will have to be pumped some distance.

Pliocene and Quaternary gravels.—These sands and gravels underlie a large portion of southern Louisiana, and should doubtless be regarded as the most important water horizon in the State. The outcrops on the hill lands are large, and therefore the amount of rainwater passing into them is great. Covered with the more recent coastal clays, they furnish artesian water over considerable areas (fig. 24), and over still larger areas (fig. 25) the water rises so near the surface that it is readily available for irrigation and other uses. In the Mississippi bottoms, and sometimes toward the coast, the water in these beds is generally so charged with various soluble salts that it is of little value. Under the main river valleys in northern Louisiana and southern Arkansas there are thick deposits of sand and gravel partially filling the old valleys. In this, limited supplies can be obtained from driven wells of no great depth, but when large supplies are needed wells should be pushed to the main gravel bed, which overlies the older Cretaceous and Tertiary strata. This can be reached at depths ranging from 75 to 150 feet.

MINERAL SPRINGS.

Although there are many small springs scattered throughout Louisiana, only three reported sales for 1902. These were as follows:

Abita Springs, Abita Springs, St. Tammany Parish.
Mandeville Springs, St. Tammany Parish.
Ozone Springs, Pearl River, St. Tammany Parish.

The total output was 499,261 gallons, with a value of $43,502.[b]

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[a] Name proposed from typical development of formation in Catahoula Parish, La., used for the lower or typical Grand Gulf of Hilgard as exposed at Grand Gulf, Miss. This formation includes the sandstone-bearing clays between the Vicksburg and Fleming Oligocene.

[b] A. C. Peale, U. S. Geol. Survey, Mineral Waters, 1902.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 123–124.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, 1902, pp. 49–50.

Subterranean waters of Louisiana, by G. D. Harris: Louisiana Geol. Survey, Rept. for 1902, pp. 205–252.

Underground waters of southern Louisiana, by G. D. Harris and M. L. Fuller: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 101, 1904.

NORTHERN ARKANSAS.

By A. H. PURDUE.

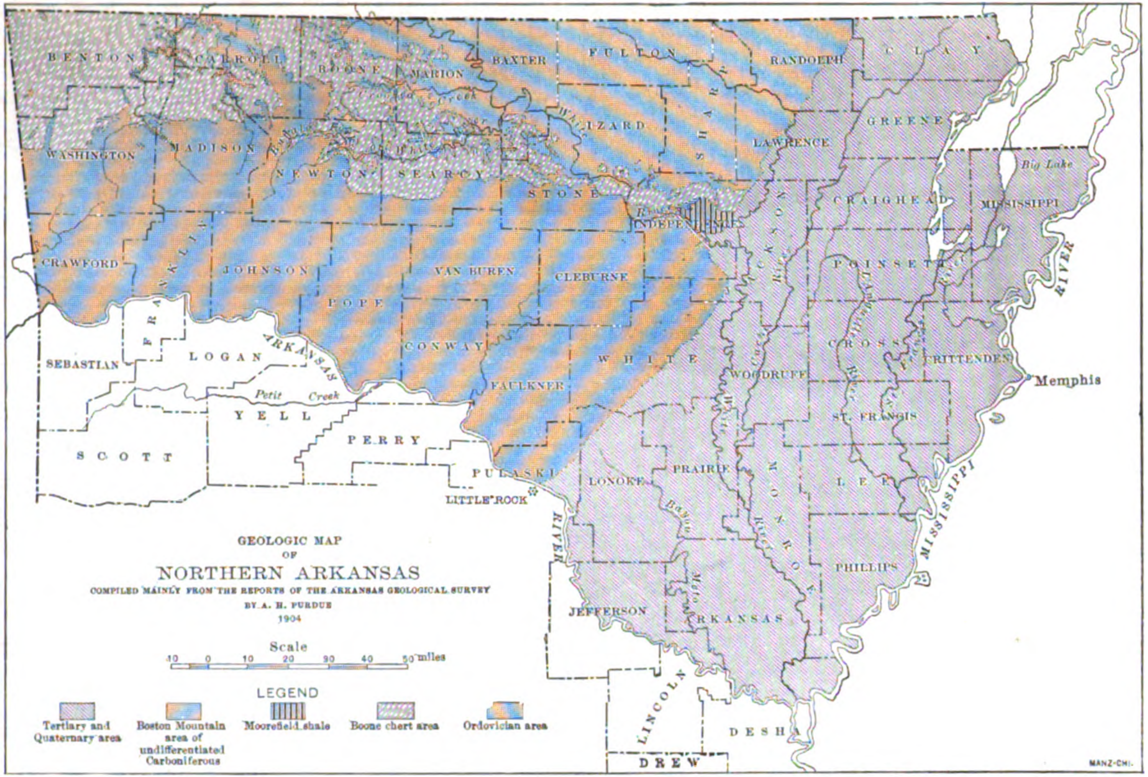
DESCRIPTION OF THE REGION.

That part of Arkansas lying north of Arkansas River comprises a little more than half of the area of the State, or about 28,700 square miles. Topographically it is divided into two well-defined areas—the eastern or lowland area and the western or highland area. The average elevation of the lowland area will probably not exceed 225 feet above sea level. The even, monotonous character of the surface is disturbed only by Crowleys Ridge, which extends northward from Mississippi River at Helena to St. Francis River at St. Francis, and into Missouri. This ridge is from 1 to 14 miles wide, and in its highest part is about 400 feet above sea level, or 180 feet above the adjacent lowlands.

The highlands are a part of the Ozark region and vary in altitude from less than 500 to 2,250 feet above sea level. They are divided into two parts, a northern and a southern, each of which is a plateau, much dissected by streams. The southern of these is the higher, and is known as the Boston Mountains. These mountains are highest in the western part of the State and gradually fall eastward, the elevation south of Batesville being 800 feet (aneroid). The Boston Mountains are separated from the lower plateau to the north by a more or less bold and irregular escarpment, the height of which varies from 500 to 1,000 feet. Figs. 28 and 29 supplement this description and aid in giving a general idea of the topography of the region.

RESOURCES.

Resources of the highlands.—The main resources of the highlands are its soil, timber, mineral deposits, and water supplies. While the really rich soil of this part of the State is confined mainly to the narrow flood plains of the valleys, much of the remainder yields fair returns, and practically all of it is well adapted to horticulture. All fruits suited to this latitude flourish. The high altitude, to which the healthful, genial climate is largely attributable, and the universal abundance of pure water have combined to make it a favorable place for settlement



GEOLOGIC MAP
OF
NORTHERN ARKANSAS
COMPILED MAINLY FROM THE REPORTS OF THE ARKANSAS GEOLOGICAL SURVEY
BY A. H. PURDUE
1904

since the early days of exploration. The rough topography has until recently prevented the extensive construction of railroads. At the present time, however, two important lines are being built and are in actual operation over a considerable part of their routes. The region contains large areas of practically undisturbed timber, fine in quality. In the northern part is a large area containing deposits of zinc ores. A thin vein of coal covers a portion of the central part of the region, and along the Arkansas Valley is an abundance of coal, which is being worked at many points. Among other mineral deposits are phosphate, manganese, building stones, and clays in great varieties.

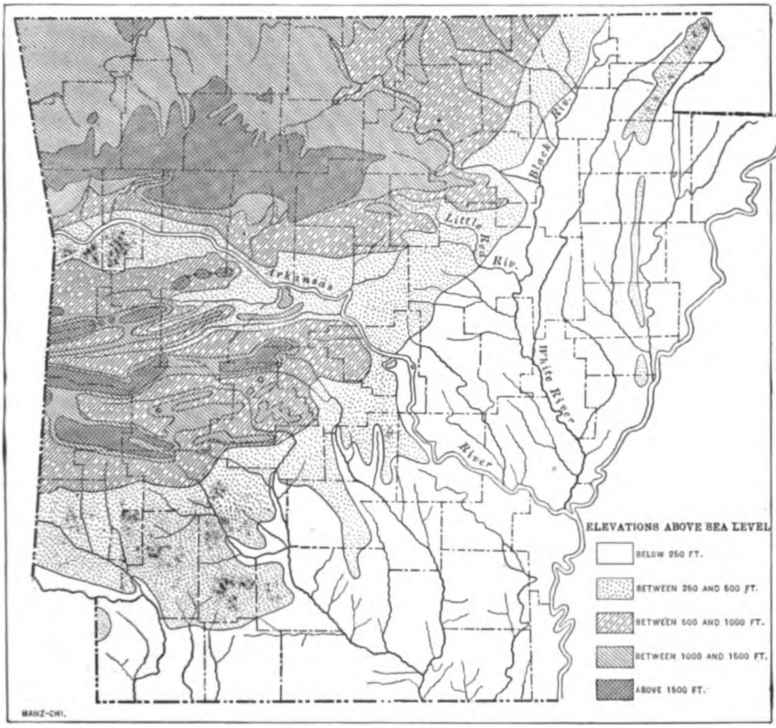


FIG. 28.—Relief map of Arkansas.

Resources of the lowlands.—The wealth of the lowland region is in its soil, timber, and waters. Much of the soil is of unusual fertility. While a great deal of the timber has been removed in recent years, a large amount still remains. As a rule, the population is densest along the river valleys, where the soil is richest, and where transportation was most easily secured in the early settlement of the State. Along Crowleys Ridge the principal towns are Helena, Marianna, Forrest City, Harrisburg, Jonesboro, and Paragould. The narrow strip of land along Arkansas River extending beyond the western border of the State is covered with flood-plain deposits, and should be considered a part of the lowlands.

GEOLOGY.

Geology of the plateau region.—The rocks of the plateau region are of Paleozoic age, and include the Ordovician, Silurian, Devonian, and Carboniferous. Ordovician rocks are exposed over a large area in the northeastern part of the division and farther west in Carroll County. They also occur along many of the stream valleys outside these areas. The rocks are of great thickness, and consist mainly of magnesian limestone, though there are a few beds of sandstone and shale.

The Silurian and Devonian rocks are exposed along the steep hillsides bordering the valleys. The Silurian consists of a limestone known as the St. Clair limestone,[a] and the Devonian of sandstone and shale known, respectively, as the Sylamore sandstone and the Eureka shale.

The Mississippian ("Lower Carboniferous") covers most of the northern division of the plateau area not occupied by the Ordovician, and consists of the Moorefield shale, the Boone chert, the Batesville sandstone, the Fayetteville shale, the Archimedes limestone, and probably some sandstone and shale above the last-named formation. The southern part of the highland area is occupied mainly by rocks of Pennsylvanian ("Upper Carboniferous") age, consisting of some limestone and a heavy deposit of sandstone and shale. The rocks are practically horizontal over the northern division of the plateau region, but from the Boston Mountains southward they fall off by monoclines and faults to the Arkansas River Valley. The structure of the southern part is not sufficiently well known to be shown in the section.

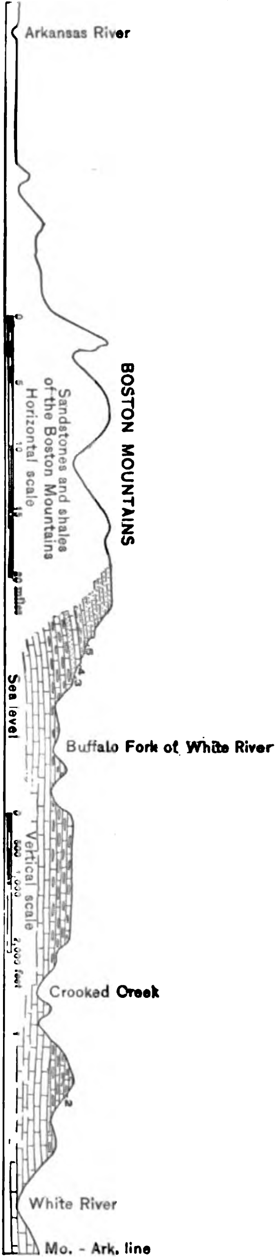


FIG. 29.—North-south profile and section from the Missouri-Arkansas line to Arkansas River, along the meridian of 92° 50'. The structure of the south half is uncertain. 1, Ordovician and Silurian; 2, Boone chert; 3, Batesville sandstone; 4, Archimedes limestone; 5, Pentremital limestone.

Geology of the lowlands.—With the exception of a sheet of alluvium over a large part of the lowland area the surface rocks of that region are of Tertiary age. They consist almost entirely of unindurated sand

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[a] The geologic nomenclature herein used is that used by the late geological survey of Arkansas.

and clay, the sand greatly predominating. The thickness of this surface deposit increases rapidly from the highland border eastward. At Newport, according to the record of a deep well near that city, on a farm owned by Mr. W. B. Chastain, it is 655 feet, that being the distance below the surface at which the Paleozoic rock was encountered. East of this point the thickness is not known.

WATER RESOURCES.

There are two natural divisions of the area under consideration which can be made on the basis of their water supplies—the Paleozoic and the Tertiary.

PALEOZOIC REGION.

The horizontal position and diversified character of the rock over the northern part of this region make the hydrologic areas conform to the areas over which water-bearing rocks are exposed or to their lines of outcrop. A detailed geologic map of the region would at the same time be a hydrologic map. Some of the water-bearing strata are exposed over large areas, others outcrop in practically horizontal planes along the hillsides. As it is not possible to present herewith a detailed geologic map, the hydrology of the Paleozoic region will be discussed under the following heads, which are somewhat arbitrarily chosen: The Ordovician area, the Boone chert area, and the Boston Mountain area.

THE ORDOVICIAN AREA.

This occupies that part of the region under consideration over which the Ordovician rocks are exposed at the surface. As previously stated, these rocks consist mainly of magnesium limestone. From these rocks, where they are cut into by streams, emerge numerous strong springs. Among these is Mammoth Springs, in Fulton County, which is said to discharge 9,000 barrels of water per minute.[a] As would be expected, the water of this region is hard, owing to the presence of the salts of calcium and magnesium in solution. The rocks are compact, and as a result the water can move only through joints and other fissures. For this reason the wells secure water only in case they strike a fissure. Some wells furnish an abundance of water, others, failing to strike fissures, are dry. The uncertainty of finding water in wells and the hard nature of the water have caused frequent resort to cisterns.

The most common method of sinking wells is by blasting out the rocks, but drilling is sometimes resorted to. So far as the chances of striking a fissure are increased by an increase of the well diameter, blasting is the most promising method. On the other hand, the chances for striking a fissure are greater in a deep well than in a shallow one, and as the cost of drilling a deep well is less than that of blasting, the former method is advisable in most cases. Especially is this true when the sanitary advantage of a well-cased drilled well over an open one is taken into consideration.

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[a] Rept. Geol. Survey Arkansas, 1891, vol. 1, p. 65.

THE BOONE CHERT AREA.

The character, thickness, and wide outcrop of the Boone chert make it the most important water horizon in northern Arkansas. It is composed of limestone and numerous lenses of much-fractured chert. Beneath the Boone chert is a limestone from 25 to 50 feet thick, known as the St. Joe marble, but for hydrologic purposes the two may be considered together. Where not removed by denudation the Boone chert usually exceeds 300 feet in thickness. It is exposed over an area of about 3,600 square miles. Solution has removed the limestone from the upper part of the formation, but the chert, being insoluble, is left as a residue on the surface, in many places several inches thick. In such places this chert débris largely reduces the run-off from the rainfall, and by so much adds to the amount of water that enters the ground. The water descends through the joints in the limestone and is transmitted horizontally through the fractures in the chert lenses. Beneath the St Joe marble over a considerable portion of the area is the Eureka shale, which, being impervious, holds the water in the overlying limestone and chert. Along lines where streams have cut their valleys down to or beyond this bed of shale, springs with a copious flow of the best water are very numerous. Most of the famous springs at Eureka Springs emerge from this horizon.

In the western part of the State, over the Boone chert area, the divides between the streams are often flat, and in such cases water is easily secured by sinking wells a few feet, but in the eastern part, where the streams have cut far down into the Ordovician rocks and have left the Boone chert on the high divides between them, water is frequently below the level to which wells can be sunk by digging and blasting, the method usually employed. On account of the considerable depth of the water beneath these high divides the drill should be employed. By this method water could be obtained in most cases.

The water from the Boone chert, while hard, contains a smaller amount of matter in solution than might be expected, owing to the fact that so much of the formation is siliceous, and consequently insoluble.

THE BOSTON MOUNTAIN AREA.

There are several water-bearing horizons in what is here designated as the Boston Mountain area. Named in their order, beginning with the lowest, the most important are: The Batesville sandstone, the Archimedes limestone, and the Pentremital limestone.

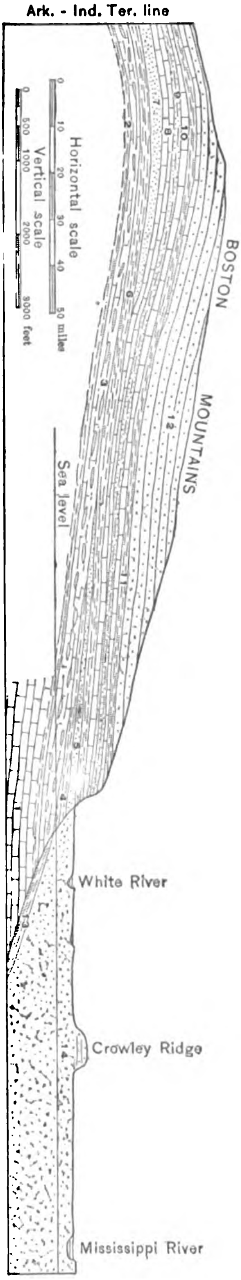

FIG. 30.—Generalized east-west section across northern Arkansas. 1, Ordivician and Silurian: 2, Eureka shale and Sylamore sandstone; 3, Boone chert and St. Joe marble: 4, Moorefield shale; 5, Batesville sandstone; 6, Fayetteville shale; 7, Wedington sandstone; 8, Archimedes limestone; 9, "Washington" sandstone and shale; 10, Pentremital limestone; 11, coal-bearing shale; 12, Millstone grit; 13, Cretaceous; 14, Tertiary.

Batesville sandstone.—The Batesville sandstone is usually brown, and consists of medium-sized grains. It is commonly in layers from 2 inches to 1 foot thick, but in some places the beds are more massive. In the eastern part of the Paleozoic area it exceeds 100 feet in thickness, but gradually thins out in the western part of the State, where in places it is altogether wanting. In the eastern part of the region it lies upon the Moorefield shale, but in the western part of the State this shale is absent, and the Batesville rests directly upon the Boone chert. Where near the surface and of considerable thickness, it forms an important water horizon, as about Green Forest, Carroll County, and at Batesville, Independence County. In both of these localities it furnishes excellent well water. At Batesville it was the chief source of water until waterworks were installed. As would be expected, the water from this horizon is soft.

Archimedes limestone.—The Archimedes limestone is a persistent formation, outcropping in an east-west direction across the Paleozoic area of the State, near the north base of the Boston Mountains. (See fig. 29.) In the eastern part of the region its thickness is 100 feet, but in the central and western parts it seldom exceeds one-fifth this amount. It is a compact limestone, composed largely of fossil remains. In places it contains lenses of chert, though these are not common. In the eastern and central parts of the area it rests upon the Fayetteville shale, a thick and impervious formation. In the western part of the State it is separated from the Fayetteville shale by the Wedington sandstone, which also contains some shale.

The massive nature of this limestone, which usually rests upon a bed of shale, causes it to form a conspicuous escarpment, from the base of which strong springs issue at frequent intervals. Below the escarpment, and upon the Fayetteville shale, is a bench from 100 yards to a quarter of a mile in width and of great fertility.

Pentremital limestone.—Above the Archimedes limestone (see fig. 29), and separated from it by a greater or less thickness of the "Washington" sandstone and shale, is the Pentremital limestone, which is also an important spring horizon, and which, like the one below it, is nearly everywhere productive along the north slope of the Boston Mountains. The water from both the last-named horizons is hard. Like most limestones, their texture is so compact that search for water in wells is not advisable.

The rocks at the tops of the Boston Mountains and of their outliers to the north are sandstone and shale. The sandstone varies in texture from medium-grained to coarse millstone grit. The porosity of the sandstone permits it to absorb a great deal of the rainfall, which is kept from sinking as underground water by the underlying impervious shale. As a consequence, the sandstones become important water-bearing strata, especially over the high, flat-topped table-lands between the heads of the mountain ravines. On these table-lands, water is easily secured from open wells. Springs frequently occur on the hill slopes, though they are neither so strong nor so numerous as along the Archimedes and Pentremital limestone horizons. Such springs are found over the large area covered by the Boston Mountains.

ARTESIAN CONDITIONS IN THE PALEOZOIC AREA.

In the lower plateau area the horizontal position of the strata precludes the possibility of obtaining flowing wells, unless it be in local and limited areas, but near the north base of the Boston Mountains, in places where the rocks dip to the south, there may be small areas where flowing wells could be secured, the Boone chert being the source of the water.

An inspection of fig. 29 will at once suggest the possibility of securing artesian water along the Arkansas Valley. The Boone chert, which is widely distributed over the northern part of the State, and forms an excellent collecting area and through which the underground water is readily transmitted, dips south with the rocks of the Boston Mountains. Though the southward extent of this formation is not known, its thickness of more than 300 feet north of the Boston Mountains is good reason for supposing that it reaches beyond the Arkansas Valley. Over the collecting area its height is from 500 to 1,000 feet above the land along Arkansas River. Over it lie the heavy deposits of Moorefield shale and Fayetteville shale. All the conditions are favorable to this formation, being the source of an abundance of artesian water in the Arkansas Valley, provided there are not many faults with an east-west strike between the Arkansas Valley and the catchment area. But it is known that faulting of the nature mentioned occurs here, and it is not improbable that it is sufficient to entirely cut off the southern flow of the water, thus destroying what would otherwise be excellent artesian conditions.

TERTIARY REGION.

The underground water of the lowland or Tertiary area has its source largely, probably mainly, in the rainfall of the region. The level surface holds the run-off in check, and sandy deposits take up a large amount of rain water, which is readily transmitted to all parts of its mass. Another source of water, unquestionably of great importance, is found in the streams which flow from the plateau region over the lowlands. When these streams are at low-water stage, the underground water moves slowly toward them from either direction. But when they are at flood stage, there is a large amount of leakage through the banks and into the loose, sandy material, for considerable distances in either direction away from the streams. The amount of underground water thus supplied to the lowlands from the Arkansas River, Little Red River, White River, Black River, and their tributaries, is problematical, but considerable. Another source of the underground water of this region is in the truncated edges of the Paleozoic rocks, beneath the younger deposits.

Owing to the low altitude, the uniformly level surface, and unindurated condition of the sediments, mainly sand, over the Tertiary area, an abundance of water can be secured almost anywhere by the expenditure of the small sum necessary to purchase from 10 to 40 feet of iron pipe, a point, a pump, and the few hours labor necessary to drive a well. The pump is usually of the kind known as the "pitcher pump," and the pipe is usually one and a quarter inches in diameter, sometimes common iron, sometimes galvanized. Because of the interlocking beds of sand and clay that in many places constitute the sediments near the surface, the depth at which water can be secured is uncertain, but it is seldom more than 40 feet. The water is most commonly raised by hand, though windmills are sometimes employed.

Formerly dug wells were the only source of water, and some of these are still in use, but they are rapidly being succeeded by driven wells. Bored wells are common in some localities. In a few instances these bored wells are cased with tile, carefully cemented at the joints to keep out the surface water, but wood is commonly employed for casing, a custom to be deprecated, as the decaying wood not only renders the water insanitary but permits the surface water to enter the well. Water for cities and ice plants is secured from bored wells 100 feet or more in depth.

The amount of water that can be supplied by almost any well is limited only by the capacity of the pipe. In cases where a large amount is needed, as for boilers of large capacity, either a pipe of sufficient diameter is used or the number of wells is increased till the desired amount of water is secured. As a rule, the water is fairly well suited for boiler use, but in some cases it forms a troublesome scale, produced by the combined deposit of the mineral matter in solution and the fine material in suspension.

The character of the water varies greatly both with depth and horizontal distance. As regards the depth to which wells should be extended, no rule can be laid down except the general one that the deeper the well the better the water. This, however, is not by any means always true, for shallow wells often furnish better water than near-by deeper ones, as where the shallow wells are wholly in a surficial deposit of sand, while the deeper ones pass into mud, which contains a great deal of organic matter and salts of iron in solution. Frequently two wells of the same depth and only a few rods apart furnish water of an entirely different character. That of one may be of good quality, while that of the other is wholly impotable. This is because near the surface there are horizontal variations in the character of the material, there being frequently intercalated deposits of mud containing a great deal of organic matter.

ARTESIAN CONDITIONS IN THE TERTIARY AREA.

The very small difference in altitude between the highest and lowest parts of this area would seem to preclude the possibility of securing artesian water in the Tertiary area, even though all the other conditions were favorable. In this area a well would probably have to pass through the Tertiary and into the Paleozoic rocks below. While the securing of artesian water from the Paleozoic horizon appears to be possible, the chances are against success. The southward dip of the Paleozoic rocks would bring these beds, if continuous, under the Tertiary deposits, in which case the chances of securing artesian water from them would be excellent. But those beds are truncated along the Tertiary-Paleozoic border to considerable depths (see fig. 30), permitting the water to leak into the younger rocks. Besides, the east-west faulting of the Paleozoic rocks, probably cutting off the southward flow of the water, would be effective over the lowlands.

MINERAL SPRINGS.

The large springs of the limestone districts of the Paleozoic area have already been mentioned. Besides these there are a multitude of smaller springs, many of which yield mineral water of value for medicinal or domestic purposes. A considerable number of them have been developed as resorts, some of which are among the most important in the country. Sanitariums using spring water are common. The waters are generally used at the spring, but in 1902 seven springs reported sales amounting to 149,100 gallons, with a value of $52,575. The springs reporting are as follows:[a]

Allen's Alterative Magnesia Spring, Hot Springs, Garland County.
Arkansas Lithia Springs, near Hope, Hempstead County.
Arsenic Spring, Hot Springs, Garland County.
Blanco Springs, near Hot Springs, Garland County.
Eureka Springs, Eureka Springs, Carroll County.
Potash Sulphur Spring, near Hot Springs, Garland County.
Ravenden Springs, Ravenden Springs, Randolph County.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 118–122.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, p. 12.

Arkansas [well and spring records], by A. H. Purdue: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, pp. 374–388.

Summary of the water supply of the Ozark region in northern Arkansas, by G. I. Adams: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, pp. 179–182.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

TENNESSEE AND KENTUCKY.

By L. C. Glenn.

TENNESSEE.

Topography.—In crossing Tennessee from east to west the following topographic divisions may be recognized: (1) The Valley of East Tennessee, (2) the Cumberland Plateau, (3) the Highland Rim or Plain within which the Nashville basin has been eroded, (4) the Western Valley of Tennessee River, (5) the Gulf Coastal Plain, and (6) the Mississippi Alluvial Plain or Bottoms.

Rainfall.—The rainfall is between 50 and 60 inches annually. In autumn, the driest season, it is 2 or 3 inches less than the average, and in winter, the wettest season, it is 2 or 3 inches more than the average; in spring it is slightly more and in summer slightly less than the average.

VALLEY OF EAST TENNESSEE.

Description.—The so-called Valley of East Tennessee is that part of the great Appalachian Valley that extends southwestward across the eastern end of the State from the Virginia to the Georgia line. Its width varies from 45 to 60 miles. It is limited on the southeast by the Great Smoky Mountains along the North Carolina line, and on the northwest by the eastern scarp of the Cumberland Plateau. The floor of this valley has an elevation of 900 feet at Chattanooga and of 2,000 feet along the Virginia line. Many long, narrow, parallel ridges trending northeast-southwest in the same direction as the valley itself rise above its floor. They are separated by long, narrow, minor valleys. The ridges are formed by the hard, upturned, folded and faulted Cambrian, Silurian, and Devonian rocks, while the intervening valleys have been eroded in the limestone or soft shale.

Water resources.—Along the eastern side of the valley the Great Smoky Range, which reaches an extreme height of over 6,500 feet, is carved along with its projecting spurs either from metamorphosed sediments of probably Cambrian age or from more ancient igneous rocks of various kinds. Among these spurs many bold freestone springs are found, and every ravine has its streamlet of pure, clear, and unfailing water. The region is rough and sparsely settled, and the springs furnish an abundant and satisfactory water supply.

In the valley proper the streams are usually broad, shallow, and rapid. Their waters are generally pure and clear, except after heavy rains. Innumerable springs are found throughout the valley. Because of the great variety in the rocks of the region the water of the springs varies greatly in character. From the limestones and dolomites large and bold springs of clear, hard but wholesome, water issue constituting the most common supply for household purposes. The waters often contain magnesian salts where the springs issue from the Knox dolomite. In general it may be said that their chief mineral contents are calcium, magnesium, and sodium carbonates, sulphates and chlorides, with occasionally iron sulphate and carbonate or aluminum sulphate or alum. Many sulphur, iron, and alum springs are found in the Devonian black shale. Sulphur waters are also found in the limestones and dolomites. Chalybeate waters occur in the sandstones and conglomerates, though freestone waters are more common. In several counties Epsom springs are known.

Some of these valley springs have earned a wide reputation for their medicinal qualities, and annually attract many visitors in search of health, recreation, or rest. A few ship their waters.

In some cases these natural supplies are supplemented by cisterns, though the abundance of springs and their unfailing flow, no doubt largely due to the faulting of the rocks, render the use of cisterns less necessary than in many limestone regions. In those towns which are without a system of waterworks the use of cisterns is more prevalent, as they furnish the only safe water supply under such conditions. In the larger cities water supplies are obtained from near by rivers or other smaller streams. Although the valley is well settled the population is largely agricultural and scattered, and stream supplies may be regarded as safe except where contaminated by tan bark, wood pulp, or other similar industries.

CUMBERLAND PLATEAU.

Description.—The Cumberland Plateau crosses Tennessee in a northeast-southwest direction, and varies in width from about 35 miles near the Alabama line to about 50 miles near the Kentucky line. Its elevation is 1,500 feet on the Alabama line, 2,000 feet in the center of the State, and 3,500 feet near Cumberland Gap. The plateau surface stands about 1,000 feet above the adjacent regions on either side. The eastern edge is an abrupt scarp that is straight for miles. The western edge is an equally abrupt scarp, but is notched by the headwaters of streams that have eaten into the plateau from the west. The surface, while measurably flat, is diversified by shallow valleys and low ridges.

Water resources.—The rocks of the plateau are of Carboniferous age. Much of the surface is underlain by sandstone, which forms an open porous soil if well drained. From this sandstone issue the numerous freestone springs that furnish so large a part of the water supply of the region. During summer and fall droughts sometimes occur, and many springs and streams decrease in volume or go entirely dry, so that water for household use and for stock becomes scarce while the small mills for grinding corn remain idle until rains set in. Open wells supplement the springs in many instances.

Supplies of water may be obtained by drilling a few hundred feet into the thick sandstone beds that underlie the larger part of the plateau. Such waters will not usually flow, but will rise within easy pumping distance of the surface. They may contain more or less iron from the sandstones or sulphur from the interbedded shales and coals. Wells drilled deeper into the underlying Mississippian or Silurian limestones or into the Devonian black shale usually obtain salt water, with greater or less amounts of natural gas or petroleum.

There are numerous chalybeate springs on the plateau, some of which are of local repute as summer resorts. Although none have been improved to any extent, the clear, cold, freestone waters, combined with the elevation and delightful summer temperature, bring many visitors from the lowlands during the heated season.

Much of the plateau is underlain by workable coal and mines are being opened at numerous places, each of which becomes the nucleus for the development of a mining town. With its growth the quality of its water supply, usually taken from open wells and springs, will deteriorate.

HIGHLAND PLAIN.

West of the Cumberland Plateau lies the Highland Plain, which extends westward to Tennessee River. The width of this plain is about 175 miles along the Kentucky line and 105 miles along the Alabama line. Its average elevation is approximately 1,000 feet. Viewed broadly, its surface is level; viewed in detail, it is gently undulating or cut by small streams into narrow but sometimes steep-sided valleys. In a few places the larger rivers, including the Cumberland, Duck, and Elk, have cut steep-walled valleys 300 or 400 feet deep and have eroded out of the very center of the Highland Plain a great oval basin 120 miles long and 50 broad, whose comparatively flat bottom is 300 to 400 feet below the encircling plain. This basin is known as the Nashville or Central basin and will be discussed in a subsequent paragraph.

PLATEAU REGION.

Description.—The siliceous beds of the Mississippian form the surface of the Highland Plain. These beds consist of limestones, siliceous shales, and chert. As they form the surface of this plain they have been exposed to the leaching action of the water so long that the calcareous matter has been removed to a considerable depth and the surface is a disintegrated mass of reddish clay and porous chert.

Water resources.—The waters of the Highland Plain are mostly of the clear freestone type, although some are chalybeate from the iron contained in the chert. Where the lime has not yet been entirely leached from the rocks the waters may be hard. Many springs are found on the Highland, although in numerous areas springs are weak or wanting, or fail during dry seasons. Many of the smaller streams dry up also. In such places deep drilling generally gives a water containing objectionable quantities of calcium and magnesium carbonates and sulphates, hence the main dependence for potable water in such cases must be cisterns, of which many are in use.

Along the eastern margin of the Highland Plain at the foot of the escarpment which rises to the Cumberland Plateau many very large springs flow from the outcrop of the flat-lying Mississippian limestones underlying the sandstones of the plateau. These limestones receive a considerable part of the drainage which emerges along the edge of the Highland Plain in streams, many of which are large enough to turn a mill where they issue from their underground channels.

In the portion of the Highland area adjacent to the central basin are many sulphur springs, while on the steep slopes between the two the springs from the outcropping black Devonian shale contain sulphur, iron, and in some cases alum. No extensive area of this slope is made up of black shale, however, as it varies from only a few feet to 20 or 30 feet in thickness. Some of the sulphur and other mineral springs on the Highland and on the slope into the basin have beeen improved and have considerable reputation as summer resorts.

NASHVILLE BASIN.

Description.—The strata of the central portion of the Highland Plain have been arched into a low oblong dome which Elk, Duck, and Cumberland rivers have eroded until they have cut through the Mississippian and Devonian and into the softer limestones and shales of the Silurian. These have been in turn eroded, resulting in the undermining of the overlying rocks of the Highland Plain and the final formation of a basin of the dimensions already given. The bottom of this basin is flat or gently rolling. It slopes somewhat toward the Cumberland and other main streams and has some isolated knobs that rise to nearly the height of the adjacent Highland, while from the rim spurs project into the basin.

Water resources.—The Silurian limestones that form the floor of the Nashville basin dip away from its center in all directions, but at such a low angle that they appear nearly flat. Many springs are found in these limestones, some of them being very large. They furnish clear, cold, hard water as a rule, though some of them contain sulphur. During the dry seasons many of the weaker springs and smaller streams go dry and difficulty is found in securing water supplies. Cisterns are extensively used, especially for household purposes, while ponds are dug or small streams dammed to secure water for stock. This region is the most fertile and most thickly populated in the State. Some cities, such as Nashville, get their water supply from rivers, others obtain water from deep wells which are pumped, while others without waterworks depend mainly on cisterns.

No persistent horizon of potable deep waters is known to underlie the basin surface. Water may be obtained almost anywhere by drilling a few hundred feet, but it is usually strongly impregnated with sulphur or is salty. In the lowest part of the basin the deep wells may flow. Several of the deep wells in Nashville are strongly sulphurous. Wells in other parts of the basin sometimes give off small quantities of natural gas, or are greatly injured by a slight exudation of petroleum. Many other wells, especially if not deep, furnish good water.

WESTERN VALLEY OF TENNESSEE RIVER.

The Highland Plain is bounded on the west by the western valley of Tennessee River, a north-south valley 400 to 600 feet deep and 8 or 10 miles wide. The rocks making the floor and most of the walls of the valley are Silurian limestones and shales, though Devonian, Mississippian, or even Cretaceous and Lafayette may in places form part of the wall. Iron and sulphur springs are numerous along the outer edges of the valley floor and in several places wells drilled years ago for salt yield an abundant flow of sulphur water, which is said to possess valuable medicinal qualities.

GULF COASTAL PLAIN.

Description.—The Gulf Coastal Plain extends from the Tennessee Valley westward to the bluffs overlooking the Mississippi River flood plain. Its width along the Kentucky line is about 65 miles; along the Mississippi line it is 105 miles. From an elevation of 600 to 800 feet in its southeastern portion its surface slopes west and northwest to an elevation of 270 feet at Memphis, and from 300 to 400 feet in the central and northwestern part of the area and along most of the bluff north of Memphis. The rocks of the region are unconsolidated sands and clays dipping gently westward, their lowest members outcropping in a narrow north-south belt just west of Tennessee River. The topography of the sandy formations is usually rolling to hilly, while that of the clays and loams is often flat when remote from streams, but hilly when near them.

Geology and water supply.—The oldest rocks of this region are the Coffee sands of Cretaceous age. They outcrop in a belt that has an average width of perhaps 4 miles and extends northward from Mississippi halfway across the State along the eastern edge of the Coastal Plain region. They overlap the Paleozoic rocks exposed in the western valley of the Tennessee. The best exposure is at Coffee Landing, on the Tennessee, where they consist of fine micaceous sands and thinly laminated dark clays with abundant lignitic material. Their base is not exposed here, but slightly over 200 feet were seen. The total thickness can not be much more than this. Westward they dip under the Rotten limestone, which is also of Cretaceous age. This latter consists of green sand and fine-grained joint clay of a leaden color and often contains an abundance of fossil shells. It forms a belt 8 or 10 miles wide extending northward from Mississippi; also halfway across the State. Its maximum thickness, 350 feet, is found along the Mississippi line, but it thins rapidly northward. The water obtained from springs and wells is in most places hard and disagreeable in taste and odor. Good water may be obtained, however, by going through it into the Coffee sand. Many such wells exist. They vary in depth according to location, the deepest being about 350 feet. Water rises nearly to the surface as soon as the Coffee sand is reached and is generally of good quality.

Next westward is a belt of sands and clays, which where they enter from Mississippi are 12 to 15 miles wide, but only about 6 miles wide where they pass into Kentucky. They are known as the Ripley beds, are of Cretaceous age, and dip gently westward. Their thickness is perhaps 400 to 600 feet. Their surface is usually hilly. They are water bearers, but open wells may go 80 to 100 feet deep for water, though in lower ground 40 to 60 feet is a common depth.

Above the sands and clays of the Ripley beds, the latest of the Cretaceous formations, lies the Porters Creek (Flatwoods) clay. This clay is of early Eocene age, and consists of light, leaden-gray clays, with occasional laminæ of fine micaceous sand. The lower part contains beds of micaceous sand, greensand, and some thin impure limestones. The formation probably has an average thickness of more than 200 feet, and extends from Mississippi northward across the State in a belt 5 or 6 miles wide. The water derived from it is not of good quality. Better water may be had by going through it and into the underlying Ripley sands.

The "Lignitic" group rests on the Porters Creek formation and extends westward across two-thirds of western Tennessee to the bluffs overlying the Mississippi. It is composed chiefly of sands, in which occur, especially in the eastern part of the area of outcrop, numerous lenses of plastic clays. In the western part of its area the upper part of the "Lignitic" is frequently marked by a bed of blue or dark lignitic clay about 150 feet thick. The total thickness of the "Lignitic" is 750 feet at Memphis. Its sands are water bearing throughout, but as they vary much and rapidly in coarseness, and consequently in quantity of water they can furnish, the proper depth of wells sunk into them must be determined by trial. Usually their lower part is the coarser, and the quality of the water yielded is generally suitable for any desired purpose. This group is by far the most valuable water-bearer in western Tennessee.

The Lafayette is spread as a thin blanket over all the preceding western Tennessee formations. It is a series of sands, clays, and gravels that are prevailingly red or orange in color and usually hardened, while in some places the sands have become cemented by iron into sandstones. The beds probably never exceed 50 feet in thickness and are more frequently less than 20 feet thick. Along the Tennessee and Mississippi River bluffs this formation consists very largely of gravel, while away from the neighborhood of these streams the gravel beds are thin or often wanting. When underlain by clays water is usually found at the base of the Lafayette. Along such of the stream valleys as cut through it numerous springs issue from these basal beds, while shallow wells may reach it anywhere. The water is usually good, provided the well is stopped in the Lafayette sand, but if it enters the top of an underlying clay or marl bed it is often poor. Over most of the region, however, the Lafayette rests on the "Lignitic" sands, and its base is then only locally water bearing, one well obtaining water while another only a few yards away may find none.

Loess overlies the Lafayette gravel in a belt 12 to 25 miles wide, extending north and south across the State. The thickness gradually decreases from 20 to 70 feet in the bluffs overlooking Mississippi River to an indefinite feather edge to the east. The loess is everywhere calcareous and wells sunk in it yield hard water. It naturally forms a rich soil and population is denser in this belt than elsewhere in western Tennessee. Many people in the loess region use cisterns, which are easily and cheaply constructed in the loess. Water of better quality may be obtained by deeper wells, drawing their supplies from the underlying sands of the "Lignitic."

Resting on the loess, and at times separable from it only with difficulty, or lying east of the loess belt and resting on the Lafayette, is a veneer of loam, clay, or sand that reaches in places perhaps 10 feet in thickness. It has generally been correlated with the Columbia. It is not of importance as a water-bearer.

MISSISSIPPI ALLUVIAL PLAIN.

In the flood plain of the Mississippi River the deposits are recent silts. These contain water at slight depths, but it is of poor quality. Its level rises and falls with the varying stages of the river. Good water may be obtained from the underlying lignitic by deep boring. Cisterns are also used, though the soft alluvial deposits are not always solid enough to prevent the walls of the cisterns from cracking.

COMMERCIAL SPRINGS.

The following springs reported sales of water in the year 1902:[a]

Eastbrook Springs, Eastbrook, Franklin County.
Hinson Springs, Hinson Springs, Henderson County.
Horn Mineral Springs, Horn Springs, Wilson County.
Idaho Springs, near Clarksville, Montgomery County.
Larkins Spring, Madison, Davidson County.
Lockeland Spring, East Nashville, Davidson County.
Montvale Spring, Montvale, Blount County.
Red Boiling Springs, Red Boiling Springs, Macon County.
Rhea Springs, Rhea Springs, Rhea County.
Tate Epsom Spring, Tate Spring, Grainger County.
Whittle Springs, Whittle Springs, near Knoxville, Knox County.
Willow Brook Spring, Craggie Hope, Cheatham County.
Wright's Epsom Lithia Well, Mooresburg, Hawkins County.

The aggregate amount sold is stated as 247,429 gallons, valued at $36,315.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 97-106.
Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, p. 49.
Tennessee [well records and spring records], by L. C. Glenn: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, pp. 358-367.

KENTUCKY.

Climatic conditions in Kentucky are much the same as in Tennessee. The topographic belts which are found in Tennessee extend northward into Kentucky, and the geologic formations of the two States are very similar. The water resources of Kentucky accordingly resemble those of Tennessee in corresponding topographic regions, so that much already said concerning the hydrographic characteristics of these belts in Tennessee applies equally well to Kentucky.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

CUMBERLAND PLATEAU.

The most eastern topographic division of Kentucky is the northward continuation of the Cumberland Plateau region of Tennessee. In Kentucky the flatness of the plateau surface, however, has disappeared, and in its stead the region is deeply dissected by streams, so that the actual surface consists of a maze of steep-sided mountains separated by almost equally narrow, steep-walled valleys. The plateau surface is represented only by the uniform altitude of the mountain crests. The southeastern edge of the plateau has an elevation of 3,500 feet, and is sharply defined by the Cumberland Mountain scarp. The western edge of the plateau has an elevation of 1,500 feet in the south, and of 900 feet along Ohio River. In Kentucky the plateau is not sharply defined on the west, but falls away in isolated projecting spurs of irregular but not great height, extending out toward the next and lower topographic division, the Lexington Plain.

The rocks of the plateau are horizontal Carboniferous sandstones and shales. Springs abound, and while in dry summers many of them, and even the smaller streams, dry up, there is generally an adequate supply of water. Some shallow open wells are used, but they furnish an insignificant part of the water supply. Some of the springs, especially such as flow from coal horizons, contain iron or sulphur. These may also at times contain alum. Population is sparse, houses are well scattered, and the springs are usually safe and wholesome. Even the simplest of sanitary precautions are, as a rule, unheard of, and occasionally water is used from a pool or branch that is utterly unfit for drinking, and doubtless the cause of a considerable amount of sickness.

LEXINGTON PLAIN.

The Highland Plain of Tennessee extends northward into Kentucky, where it is known as the Lexington Plain. In detail its elevation varies considerably but it may be taken as averaging 1,000 feet in its eastern and central parts and 800, 600, or even 400 feet along Ohio River. The surface of much of this Lexington Plain is composed of Mississippian and Devonian sandstones, shales, and limestones.

In sandstone regions the water is usually soft, and springs are more abundant and constant than in the shale or limestone areas. In the Devonian black shale, sulphur, alum, and copperas springs are often found. In the limestone areas much of the drainage is underground, and at many places big springs occur, some of which are so large that they furnish an abundant supply of water for good-sized towns. Such waters are hard.

In the north-central portion of this Lexington Plain there is an oval-shaped area of 10,000 square miles with Frankfort almost in its center that is composed of Silurian limestones similar to those of the Nashville basin. Much of the drainage is underground, the water is hard, and springs are scarce in some portions. Water may be obtained by drilling generally at very moderate depths but it almost always smells slightly of petroleum or contains salt or other mineral matters rendering it unfit for domestic purposes. Streams dry up in the summer and ponds are dug to hold water for stock. Cisterns are very largely used.

Numerous mineral springs are found in the limestone region, some of which are noted health and summer resorts. They usually contain sulphur, iron, salt, or calcium and magnesium carbonate and sulphate.

In western Kentucky, on either side of the lower part of Green River, Carboniferous sandstones and shales are exposed in an oval area of 4,000 square miles which belongs topographically to the Lexington Plain but whose water supplies are in general much like those of the Cumberland Plateau region. Stream cutting has not been so deep as in the eastern part of the State and springs are somewhat less abundant, although sulphur and iron springs are numerous.

GULF COASTAL PLAIN.

That part of Kentucky which lies west of Tennessee River is known as the Jackson Purchase region. It is an area of unconsolidated sands and clays belonging to the Gulf Coastal Plain and forming a continuation of the similar area in western Tennessee.

Of the Cretaceous formations of Tennessee only the youngest, the Ripley, extends north into Kentucky. The Ripley sands and clays lie within 3 or 4 miles of Tennessee River and form a belt 5 to 10 miles wide. The formation is porous and open and becomes very dry during summer, so that open wells must frequently be sunk to a depth of 80 to 100 feet to insure adequate supplies. Cisterns and artificial ponds are extensively used. On the west the Ripley formation dips beneath the Porters Creek (Flatwoods) clay (basal Eocene), which gives more of a flatwood aspect to the topography here than it does in Tennessee. As in Tennessee, the water found in it is hard, "flat tasted," and not abundant. The thickness of the Porters Creek clay in Kentucky is not known, but it is probably not over 200 feet. It forms the surface in a belt 5 to 15 miles wide. Better water could be obtained in this area from the underlying Ripley sands, but the water probably would not flow except in very low places, though it would commonly rise nearly to the surface.

The western three-fifths of the Purchase region is composed of "Lignitic" sands and clays in which the coarser sand beds are water bearing. They are of variable character, however, and no one coarse stratum seems widely persistent. In the eastern part of the "Lignitic" area good water should be found within 200 to 300 feet of the surface. At Mayfield, for example, excellent water is obtained at a depth of 250 feet. Near Mississippi River the depth will increase to 500, 600, or 700 feet, and the sands tend to become finer and less reliable as water bearers.

Lafayette sand and gravel, loess, Columbia loam, and Mississippi flood-plain alluvium all occur very much as they do in Tennessee, and bear similar relations to water-supply problems.

COMMERCIAL SPRINGS.

The following springs reported shipments of water in 1902:[a]

Anita Spring, Lagrange, Oldham County.
Bedford Springs, Bedford, Trimble County.
Bluelick Springs, Bluelick Springs, Nicholas County.
Crab Orchard Springs, Crab Orchard, Lincoln County.
Upper Bluelick Springs, Nicholas County.

The aggregate sales are given as 169,750 gallons, valued at $21,537.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 106–118.

Preliminary list of deep borings in the United States, Pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 47–49.

Kentucky [well and spring records], by L. C. Glenn: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, pp. 369–373.

Water resources of the Middlesboro-Harlan region of southeastern Kentucky, by G. H. Ashley: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, pp. 177–178.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

MISSOURI.

By Edward M. Shepard.

GENERAL CONDITIONS.

Missouri has an abundant supply of potable waters, which, for the most part, come to the surface in springs generously scattered over a large portion of the southern half of the State, and to a less degree over the northern half.

North of Missouri River the country is covered by glacial drift, varying from a few feet to 150 feet in thickness. In this area the springs are small, but they occur frequently where erosion has cut into the drift, which thus becomes the main reservoir for the wells and springs of the region.

South of Missouri River the country is destitute of drift, but erosion has cut deep valleys along the borders of the Ozark Plateau, and in such localities some of the largest and finest springs of the country abound.

TOPOGRAPHY.

Topographically, Missouri may be naturally divided into four great districts: (1) the Northwest Plateau, (2) the North-Central Plain, (3) the Ozark-St. Francis Dome, and (4) the Southeastern Lowlands, all of which are outlined on fig. 33.

The first district, the Northwest Plateau, includes the elevated portion in the northwestern third of the State, and is bounded on the southeast by the 900-foot contour. This plateau rises gently to the northeast corner of the State, where an elevation of over 1,200 feet is reached. The strata generally dip from 10 to 15 feet to the mile, in a northwesterly direction, thus burying to a considerable depth the Coal Measures which outcrop on the southern border of the district.

The south boundary of the second division, or the North-Central Plain, starts arbitrarily on Mississippi River in St. Charles County, runs southwesterly until it joins the north boundary of the Ozark-St. Francis Dome (at approximately the 900-foot contour) in Franklin County, which it follows to the northwest corner of Barton County on the Kansas line.

The Ozark-St. Francis Dome district is included in the large area between the last-described line and a line extending southwest from

Cape Girardeau to the Arkansas boundary, following the 400-foot contour.

The Southeastern Lowlands include the southeastern corner of the State south of the 400-foot contour, and nowhere have an altitude much exceeding 400 feet.

GEOLOGIC CONDITIONS.

The Northwest Plateau is covered wholly by drift, which is underlain by the Lower and Upper Coal Measures. The North-Central Plain is partially covered by drift in the northeast, and underlain by Mississippian and Lower Coal Measures, with a fringe of Devonian and Silurian on the eastern border. The Ozark-St. Francis Dome varies greatly in altitude and in geology. The St. Francis Mountains are made up of Algonkian granite and porphyry. The greater portion of the Ozark region is underlain by Cambrian rocks, composed of alternating beds of dolomites and sandstones. The southeastern lowlands are underlain almost entirely by the sands, clays, and gravels of the Tertiary.

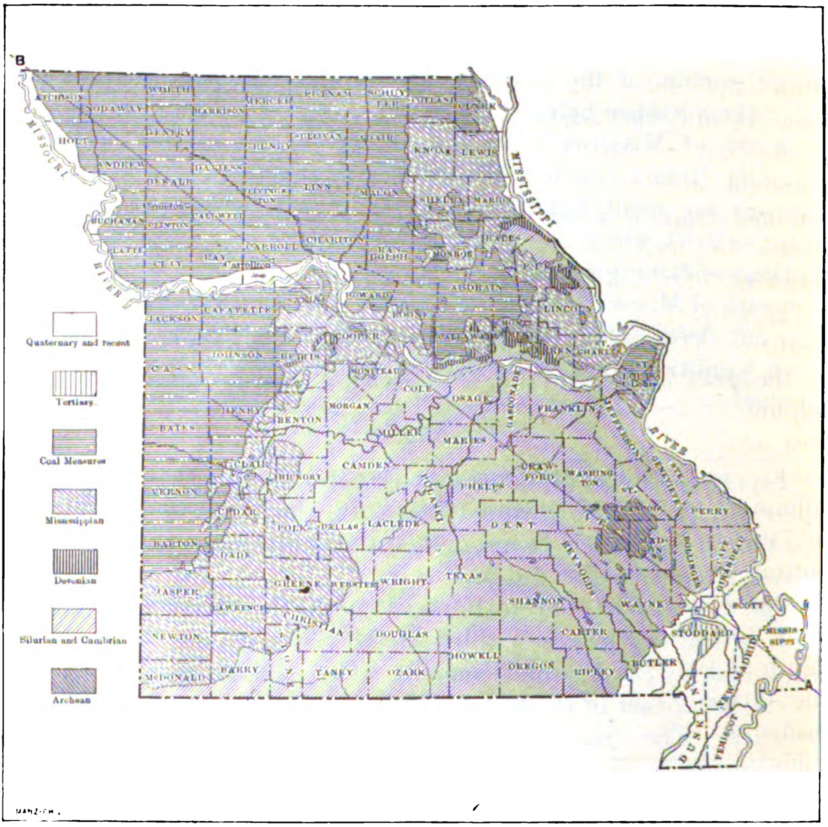

FIG. 31.—Geologic sketch map of Missouri.

CHARACTER OF THE WATER SUPPLY.

NORTHWESTERN PLATEAU DISTRICT.

The rocks underlying this district belong entirely to the Lower and Upper Coal Measures. The underground water supply of this region is mainly derived from the drift. In the counties bordering the Missouri River, especially Atchison County, small springs are frequent in the bluffs, often occurring one-third of the way to the top. They are also frequent along the valleys of many of the streams. In the greater part of this district drills have shown that the basal stratum of the Coal Measures is a porous sand rock containing occasional beds of bituminous shale, similar to the shale and sandstone forming the basal member (Cherokee shales) of the Coal Measures elsewhere in the State. An abundant supply of water is nearly everywhere obtained from this sandstone by drilling, as is shown by well records furnished by Mr. R. Hawkins, of Chillicothe.

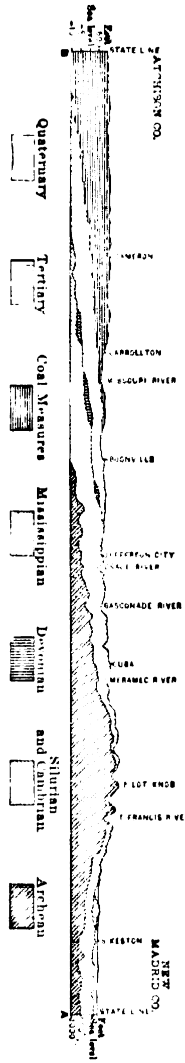

FIG 32.—Ideal cross section through Missouri.

The water from this stratum in widely different localities uniformly carries about 400 grains of salt to the gallon, with some iron, and occasionally sulphur. Mr. Hawkins states that farmers in this area agree that this is very good water for live stock. The pressure is sufficient in Livingston and adjoining counties to cause the water to rise 725 to 740 feet above sea level. Along Grand River bottom the water flows sluggishly out of the wells. As the rocks dip irregularly to the west and north from 10 to 15 feet to the mile the approximate depth of the water stratum may be calculated if the surface elevation is known and allowance is made for the local disturbances producing irregular folds in the strata. The water-bearing stratum varies from 20 to 70 feet in thickness and furnishes an abundant supply of water. Below this water level of the Cherokee shales and sandstones are other water-bearing strata, but, as a rule, they become more highly impregnated with mineral salts as the depth increases, until they are no longer potable.

A few small artesian districts are found in this area. At Tarkio, Atchison County, are seven small flowing wells, varying in depth from 196 to 220 feet. Some of these furnish the city with water. They are evidently derived from higher reservoirs in drift gravel, overlain by an impervious clay layer. Another flowing well at Bethany, 684 feet deep, furnishes water for the Heilbron Sanitarium. It flows 5 gallons per minute. The source is near the bottom of the well, in the Upper Coal Measures. Another flowing well is reported at Gallatin, Davis County, which probably obtains water from the Upper Coal Measures. There is also a flowing well at G. H. Lawson's, near Utica, Livingston County. The surface elevation here is about 750 feet. The water is saline, and derived from sand rock of the Cherokee shales. The well is 421 feet deep, and drilling was stopped in Mississippian limestone. The water flows sluggishly from the top. There are a number of mineral springs and drilled wells supplying mineral waters in this district, some of which have a national reputation. One of the most noted and popular of these is Excelsior Springs, in the northeast corner of Clay County, about 30 miles northeast of Kansas City. In the group of springs at this place the best are the Regent and Siloam springs, both ferromanganese waters, derived from the Coal Measures shales. Two drill wells—the "Sulpho-saline," 1,460 feet deep, and the "Salt-sulphur," 1,370 feet deep—have been sunk in this vicinity, furnishing sulpho-saline waters. No record of these two wells has been preserved, but the writer believes that the waters

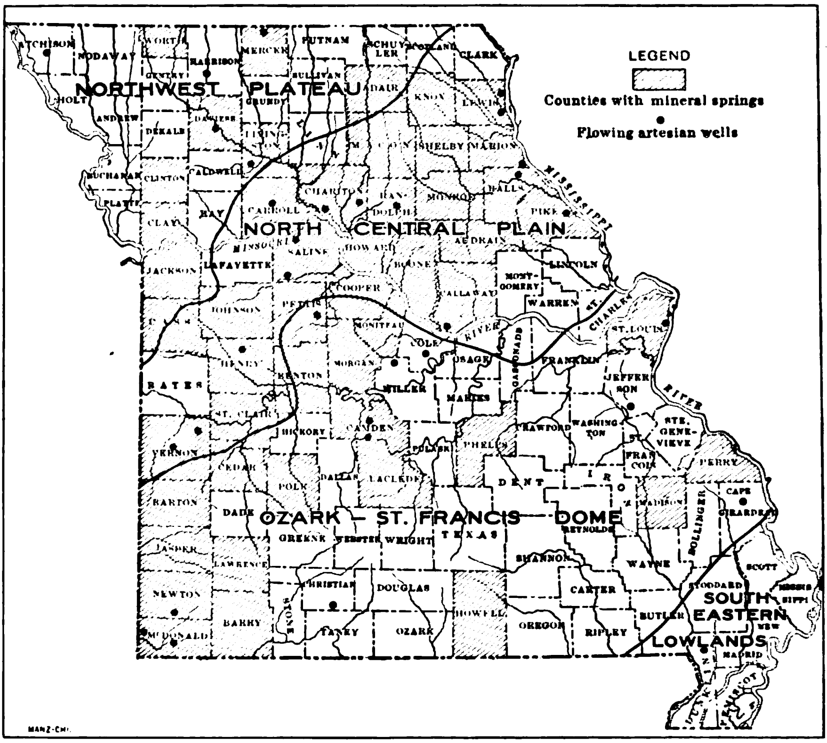

FIG. 33.—Sketch map of Missouri, showing water resources.

are derived from the Jefferson City limestone (Second magnesian, of Swallow). The waters are carbonated and shipped to all parts of the country. Winslow has shown[a] the similarity of the Excelsior Springs waters to those of St. Moritz and Mont d'Or in Switzerland and France.

Cities in this district generally derive their water from adjacent rivers. Wells and cisterns are the most common source of potable water. The former are shallow, from 20 to 50 feet deep, and generally have an abundant supply of water from the drift gravels. Broadhead makes the following statement:[b] "Wherever limestone No. 78 [Bethany limestone] of the Upper Coal Measures prevails we may expect good streams of water just beneath. Springs of any kind are not common in either the Middle or Lower Coal Measures, but are more frequently found where the Upper Coal Measures prevail."

NORTH-CENTRAL PLAIN DISTRICT.

The greater part of this district is underlain by Lower Coal Measures and Mississippian rocks. Fresh-water springs are not very common, especially in the Lower Coal Measures. Salt and mineral springs, some of unusual size, abound. As regards the distribution of underground waters, the district is naturally divided into three sections—the eastern, middle, and southern. The eastern section is largely overlain by drift. Small springs are found at the base of rounded hills of drift and occasionally along outcroppings of the Burlington and Louisiana limestones, and in Warren County good springs are found at the base of the St. Peter (First) sandstone. The main dependence for water in this section, however, is in shallow wells in the drift and in cisterns. In the central section fresh-water springs are rare, and potable water is mainly derived from wells and cisterns, the wells being dug in loess, where that formation occurs. Good water may also be found in the limestones of the Henrietta or the sandstone of the Marais des Cygnes (Pleasanton) shales. This section is noted for the enormous brine springs which are so frequent in Saline and Howard counties. Around some of these brine springs buffaloes in the past have licked away the soil to a remarkable degree. At McAllister Springs is an old buffalo lick, where a valley approximately 25 feet deep, 200 feet long, and 100 feet wide has been excavated. These springs have become popular resorts.

The Big Salt Spring, in Saline County, is a remarkable example of one of these brine springs. The surface rock is near the base of the Mississippian, and the spring proper is an oval pool about 25 feet in diameter. The water boils up all over the surface of this pool, and is impregnated with sulphur. Its source is undoubtedly at a great depth.

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[a] Missouri Geol. Survey, Report on mineral waters, vol. 3, Schweitzer, p. 202.

[b] Missouri Geol. Survey, vol. 1, 1873-4, p. 37.

This spring exhibits a curious fluctuation in temperature. Meek described it in 1855, in his Geological Report on Saline County, as having a temperature of 60°, and as containing an abundance of sulphureted hydrogen. Woodward visited it in 1890 and in his report on The Mineral Springs of Missouri described it as having a temperature of 56°, with little or no sulphureted hydrogen. The present writer visited it in 1903, when he found the temperature to be 64°, with considerable sulphureted hydrogen. Data from these three observations also indicate a steady decrease in the flow of this spring. The temperature obtained by Meek in springs in other localities checks closely with the data obtained by the present writer; therefore the variation is probably not due to difference in thermometers. Meek describes another brine spring adjoining this one as subject to sudden large fluctuations in flow, independent of rains or droughts. He states, "I had the satisfaction to see it in the act of rising. The water was seen to suddenly rise and flow out over perfectly dry ground." This central section seems to be a basin which receives the flow from the Ozarks from the southeast, being apparently inclosed on the south by the Sedalia fold, and probably on the west by smaller folds which have not yet been fully outlined. If this view can be fully verified it might account for the concentration of salines in these waters. The presence of a considerable amount of calcium chloride in all the deep wells and brine springs of this district would presuppose the theory that this was a basin early shut off from the sea, in which the original sea water became concentrated. This section is the most prominent artesian region in the whole State, and will be referred to later. The southwestern section of this North-Central Plain contains a few weak springs, and these are frequently impregnated with alum, sulphur, epsom salts, and sometimes with ferrous sulphate. These are especially noted in Bates, Vernon, and Barton counties. They are mainly derived from the Cherokee shales, which are frequently pyritiferous and magnesian. A number of valuable chalybeate springs are found in this section; they issue from the basal sandstone of the Cherokee shales.

As before stated, this North-Central Plain contains the main artesian areas of the State. In the eastern section of the district an artesian belt extends along the eastern slope of the Winfield-Rensselaer fold. The writer has traced this fold as far north as Rensselaer and believes it to extend still farther north into Lewis County. At Canton, in Lewis County, is an artesian well 906 feet deep, which was sunk in 1890. The first flow of water was struck at 870 feet, in the St. Peter sandstone (First sandstone of Swallow). Sixty feet of this porous sandstone was passed through in the bottom of this well. A gage at the mouth of the well indicates a pressure of 12 pounds. This well supplies the city with water and is leased by Messrs. Griffith and Maggard, who ship large quantities of the water abroad. This is one of the finest sulpho-saline waters in the State. The well is located on a high bluff overlooking Mississippi River and is surrounded with every adjunct for making a popular health resort. Two other artesian wells were sunk at Lagrange to a depth of 800 and 850 feet. Both obtained their flow from the St. Peter sandstone (First sandstone of Swallow). The water from these is mildly sulpho-saline and is largely shipped to Chicago and other points in Illinois. South of Lagrange, at Hannibal, in Marion County, two other flowing wells were struck at a depth of about 900 feet, the waters being also sulpho-saline, but neither is utilized commercially. Still farther south, at Louisiana, in Pike County, is another sulpho-saline artesian well, strongly impregnated with sulphureted hydrogen. This well is 1,350 feet deep and its flow is very strong. The log of the well has been lost, but it is believed that the main flow comes from the St. Peter sandstone (First sandstone of Swallow).

One of the most interesting wells in the State, and probably one of the oldest drill wells in the United States, is the Spaulding artesian well in the north part of Ralls County, 10 miles west of Hannibal. It was drilled by hand to a depth of 300 feet about 1823, by the Government, in search of brine for the manufacture of salt. The water is very strongly impregnated with salt and sulphureted hydrogen. The flow is very strong and has never perceptibly decreased. The source of the water is undoubtedly St. Peter sandstone (First sandstone of Swallow), as this horizon outcrops in greatly tilted beds a mile to the southeast. A hotel, lake, bath house, and pleasure grounds adjoin the well.

At Bowling Green, in Pike County, the B. B. springs carry 569 grains of mineral matter to the gallon, 475 grains of which are magnesium sulphate. The water is derived from Hannibal shales. Not far distant from these are the Iris and Ionian springs, and the Kalinat well, owned by Mr. L. R. Stevens. The Kalinat water is somewhat similar to the B. B. water in composition, and probably has its source in the Hannibal shales.

This central district has already been referred to as the main artesian region in the State. Wells of this character are located at Huntsville, Randolph County; Salisbury and Brunswick, Chariton County; Carrollton, Carroll County; Sebree, Howard County; Sweet Springs and Malta Bend, Saline County, and Smithton, Pettis County. The Carrollton well is 241 feet deep. The principal flow of saline water was struck at a depth of 200 feet, at the base of the Cherokee shales. The Brunswick well, of sulpho-saline water, is 1,500 feet deep and was sunk at a cost of $1,500. Its probable source is St. Peter sandstone (First sandstone of Swallow). A strong flow of very salt water was struck at 600 feet, probably in the Cherokee shales, but this was shut off by casing. The Salisbury artesian well, also sulpho-saline, was sunk by the city to a depth of 852 feet and at a cost of $2,500.

At Malta Bend, in Saline County, an artesian well was sunk to a depth of 1,250 feet. The first flow, strongly charged with salt and sulphureted hydrogen, was struck at 640 feet, in Cherokee (?) shales. At 840 feet a stronger flow of salt water was struck in sandstone (St. Peter sandstone?). At Sweet Springs a strong flow of sulpho-saline water, estimated at 840 gallons per minute, was struck in a well 1,074 feet deep. The cost of this well, $3,000, was raised by subscription. Excepting a few chalybeate springs, the most notable springs in the central district are the Sweet and McAllister springs. A few years ago the former was a noted resort in the State, with a fine hotel and park. Since the burning of the hotel the property has depreciated, but the mildly saline water is still shipped from the bottling works. The McAllister springs are in a group located about 5 miles from Sweet Springs, the more important of them being the Black Sulphur and two salt springs situated in the old buffalo lick previously described. The conditions for well water are similar to those mentioned in the Lower Coal Measures of the eastern section.

In the western section of the North-Central Plain, on the western flanks of the Ozark dome, are two groups of artesian wells, one at Clinton, in Henry County, the other in Vernon County, at Nevada and Smithton. The writer is indebted to Dr. J. H. Britts, of Clinton, for records of the seven wells, five of them flowing, which were sunk at that place. Well No. 1 was sunk to a depth of 800 feet. At 425 feet a flow of 200 gallons per minute was obtained from the Moreau (Second) sandstone. At 800 feet a flow of 400 gallons was obtained from the Gunter sandstone (Third sandstone). Well No. 7, sunk to a depth of 818 feet, flowed 1,000,000 gallons daily, surpassing all the others combined. It derives its supply from the Gunter sandstone. This well, which yields a slightly alkaline sulphur water, furnishes an abundant supply for the city. Three of these wells are adjacent to one another, and their surplus waters form a beautiful lake, which, with a hotel and park, make a fine pleasure resort.

At Nevada, Vernon County, a well was sunk to a depth of 900 feet, at a cost of $2,500. The principal water was reached at a depth of 550 feet, probably in the St. Peter sandstone. A beautiful park and lake surround this well. Another small artesian well is located at Smithton, in the same county.

The three beds of limestone of the Henrietta formation and some of the sandstone beds of the Cherokee shales are all water bearers and supply good waters.

OZARK-ST. FRANCIS DOME.

This is an area of decided uplift that extends from Missouri River to the Red in Arkansas, and from the Mississippi into Indian Territory. The rocks dip gently in every direction from the elongated axis. Erosion has cut deep valleys, especially on the eastern side. The two highest points are Taum Sauk, in the St. Francis Mountains, where an elevation of 1,800 feet is reached, and Cedar Gap, in Wright County, 1,700 feet above sea level. Structurally this area is somewhat complex, divergent anticlines merging into the main fold. There is strong evidence of two distinct periods of elevation. In the St. Francis Mountains the granites and porphyries are, it is believed, of Algonkian age. The major portion of the Ozarks are alternating beds of sandstones and dolomites belonging to the Silurian and Cambrian. Bordering these sandstones and dolomites are narrow belts of Devonian and Mississippian rocks. This is preeminently a district of great springs and caverns. In the St. Francis region, however, springs in the crystalline rocks are extremely rare. Considered geologically, the lowest water-bearing horizon, and the most prominent one in the State, is the Gasconade limestone (Third Magnesian). This has a maximum thickness of 500 feet, is frequently cavernous, and some of the largest springs in the country flow from it.

Mammoth Spring, in Arkansas, for example, just over the State line, with its source in Missouri, has a flow of 226,195,200 gallons per day. This is one of the largest springs in the world. Bennett's or Bryce's spring, in Dallas County, has a flow of 161,568,000 gallons per day. Ha Ha Tonka or Gunter's spring, in Camden County, has a flow of 158,982,000 gallons per day. Other immense springs are found in this formation. Greer Spring, in Oregon County, is reported by Prof. H. B. Shaw, of Missouri State University, in his paper on The Water Power of Missouri, published by the university press, to have a flow of 42,000 cubic feet per minute. Meramec Spring, in Phelps County, is reported by the same authority to have a flow of 7,500 cubic feet per minute. Double Spring, in Ozark County, the Waynesville and several other springs in Pulaski County, and a number in Miller, Crawford, and Morgan counties swell this record. As would be expected, great caves and enormous sink-holes abound, the latter marking the course of underground channels. The underground channel of the stream probably forming Mammoth Spring, in Howell County, is outlined by the "Grand Gulf," a wonderful sink three-quarters of a mile long by 200 feet deep. From the bottom of this chasm a cave leads into a more recent channel, exposing the stream, which flows out as Mammoth Spring. The water from this formation is clear, cold, moderately hard, and carries from 10 to 15 grains per gallon—mainly lime and magnesian carbonates.

The Trenton limestone is a prominent water-carrier in Jefferson County. The "Big" or "House's" spring may be mentioned as an example from this horizon.

In the Delthyris shales, of the upper Silurian, springs are particularly abundant and in Perry County are often large.

In the Chouteau group are found weak but highly mineralized springs. Next to the Gasconade limestone, the Burlington limestone is the most important water-bearing horizon in this area. Caves and large springs of remarkable purity, carrying from 15 to 20 grains of carbonates of lime and magnesia to the gallon, are found everywhere in the horizon, notably in Greene, Lawrence, Newton, McDonald, Barry, and Christian counties.

The St. Louis limestone, besides being cavernous, includes some large springs.

While only the more prominent water-bearing strata have been mentioned, it might be said that small but pure cold springs are numerous in all the formations of the Ozarks. A few chalybeate springs, issuing mainly from ferruginous sandstones, are found throughout the district. A few sulpho-chalybeate springs of considerable value issue from the Graydon sandstone of the Mississippian, notably those at Graydon and Eudora Springs, in Polk County, and at Paris Springs, in Lawrence County. Several cities in this district derive their water supply from large springs. Springfield, a city of 32,000 inhabitants, is supplied entirely from the Fulbright Spring, which issues from the Burlington. This remarkably pure spring carries only about 10 grains of mineral matter, mainly calcium carbonate, to the gallon.

A few small artesian wells are found in this district in McDonald, Newton, Christian, Camden, Miller, Cole, Jefferson, and Cape Girardeau counties. In St. Louis County is found a particularly interesting artesian basin, formed by Ordovician and Mississippian rocks dipping strongly underneath a patch of surface Coal Measures in the center.

SOUTHEASTERN LOWLANDS.

In this district the question of pure drinking water has been a serious problem. There are practically no springs. The country is low and frequently swampy, and the surface water contains considerable organic matter. The discovery of artesian water in a well sunk about one year ago at Campbell, Dunklin County, to a depth of 910 feet now points to an easy solution of this difficulty. The first flow of water in this well was reached at a depth of 135 feet, but the principal source was found at the bottom of the well. The water is soft and slightly charged with sulphur.

COMMERCIAL SPRINGS.

Besides being used as resorts or as adjuncts to sanitariums, 18 or more springs place the waters on the market. In 1902 these springs, a list of which is given below, reported shipments of 963,545 gallons, valued at $204,270.[a] The water is used for table and medicinal purposes.

Akesion or Healing Spring, Sweet Springs, Saline County.
American Mineral Springs, St. Louis County.
B. B. Mineral Springs, Bowling Green, Pike County.
Blue Lick Springs, Blue Lick, Saline County.
Browns Lineville Springs, Mercer County, near Lineville, Iowa.
Eldorado Springs, Eldorado Springs, Cedar County.
Excelsior Springs, Excelsior Springs, Clay County.
Haymakers Lineville Springs, Mercer County, near Lineville, Iowa.
Jackson Lithia Spring, Jackson County.
Lineville Mineral Springs, Mercer County, near Lineville, Iowa.
McAllister Springs, McAllister, Saline County.
Magnesia Gusher Spring, Canton, Lewis County.
Monegaw Springs, Monegaw Springs, St. Clair County.
Mysterious Medical Spring, Canton, Lewis County.
Ponce de Leon Well, Desoto, Jefferson County.
Randolph Springs, Randolph Springs, Randolph County.
Sweet Springs, Sweet Springs, Saline County.
Windsor Spring, Windsor, St. Louis County.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 164–170.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 58–59.

Mineral waters of Missouri, by Paul Schweitzer: Missouri Geol. Survey, vol. 3, 1892.

Missouri [well and spring records], by E. M. Shepard: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, pp. 389–440.

Spring system of the Decaturville dome, Camden County, Mo., by E. M. Shepard: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 110, pp. 113–125.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

IOWA.

By William Harmon Norton.

The underground water resources of Iowa are of two classes. The first includes those bodies of ground water which are fed by the local rainfall and are reached by common wells, or issue as springs wherever the ground-water surface is reached by valleys. Artesian waters, the second class, comprise the more deeply circulating waters which move under pressure through permeable layers of the earth's crust.

SHALLOW SUPPLIES.

On account of the abundant rainfall of the State, there appears to be no considerable area where the waters of the first class are not found within easy drilling distance in quantities sufficient at least for domestic and farm uses. Their distribution, however, is governed by certain geologic conditions which will be briefly sketched.

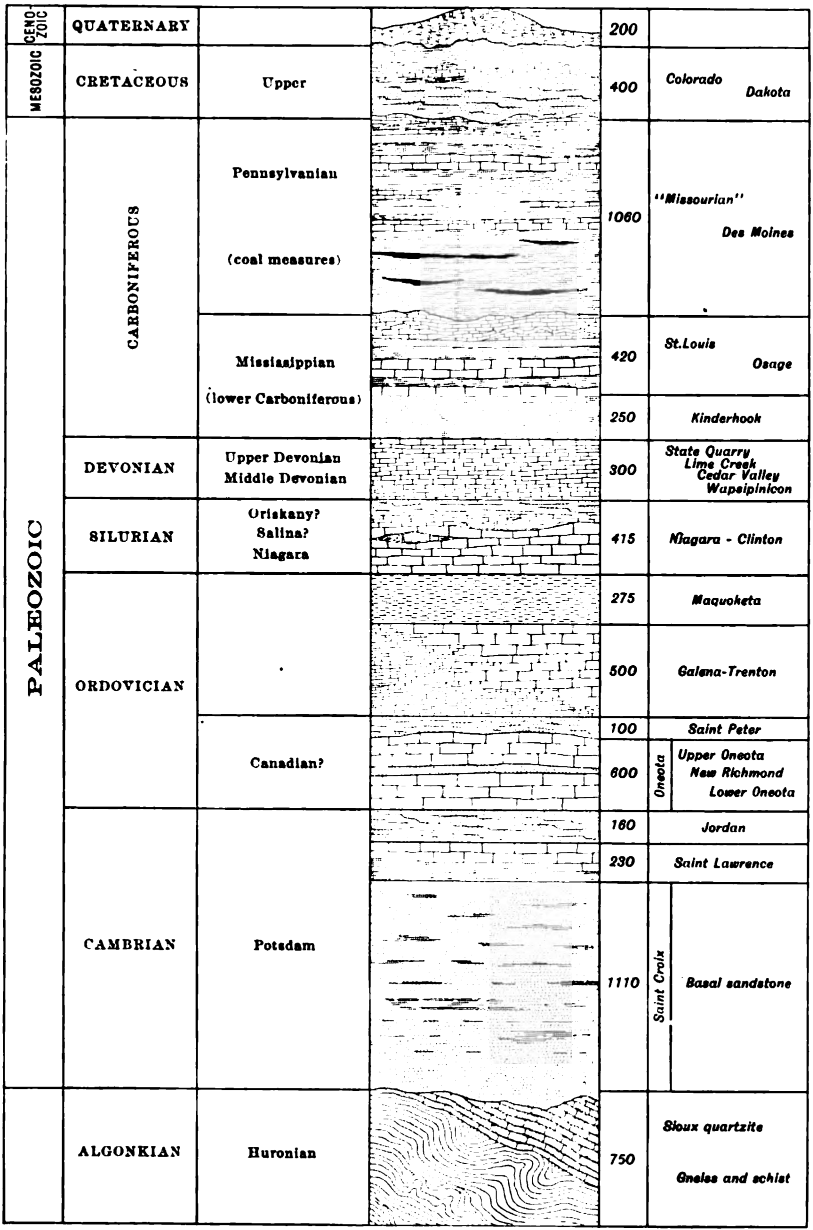
THE DRIFTLESS AREA.

This area includes a relatively small tract in northeastern Iowa which was never covered by the various ice sheets which spread deposits of drift over the remainder of the State. Its maturely dissected surface has a greater relief than exists elsewhere in Iowa, having a maximum range of 600 feet. The ground water level lies low within the steep-sided and narrow ridges. The limestones which in part form the surface of these uplands are pitted with sinkholes through which the rainfall drains into cavernous passages and rapidly finds way to underlying massive and porous sandstones of great storage capacity, which supply copious springs wherever they are cut by the valleys.

WATERS OF THE DRIFT.

Outside the driftless area the State is covered with sheets of drift of various age. The most recent is the Wisconsin drift sheet, occupying the north-central portion of the State. It presents a surface with countless undrained depressions and streams which have hardly begun the work of erosion. Ground water here stands high, and exuding in the sags gives rise to the many lakelets and the extensive sloughs of the region.

The Iowan drift sheet, which forms the surface in the northeastern portion of the State, has a topography that is somewhat older than that of the Wisconsin, the lakelets and sloughs having been largely drained by the natural erosion of the streams.



CENOZOIC	QUATERNARY		200	
MESOZOIC	CRETACEOUS	Upper	400	*Colorado* *Dakota*
PALEOZOIC	CARBONIFEROUS	Pennsylvanian (coal measures)	1060	*"Missourian"* *Des Moines*
		Mississippian (lower Carboniferous)	420	*St. Louis* *Osage*
			250	*Kinderhook*
	DEVONIAN	Upper Devonian Middle Devonian	300	*State Quarry* *Lime Creek* *Cedar Valley* *Wapsipinicon*
	SILURIAN	Oriskany? Salina? Niagara	415	*Niagara - Clinton*
	ORDOVICIAN		275	*Maquoketa*
			500	*Galena-Trenton*
		Canadian?	100	*Saint Peter*
			600	*Oneota*: *Upper Oneota* *New Richmond* *Lower Oneota*
	CAMBRIAN	Potsdam	160	*Jordan*
			230	*Saint Lawrence*
			1110	*Saint Croix*: *Basal sandstone*
	ALGONKIAN	Huronian	750	*Sioux quartzite* *Gneiss and schist*

Fig. 34.—General geologic section of Iowa.

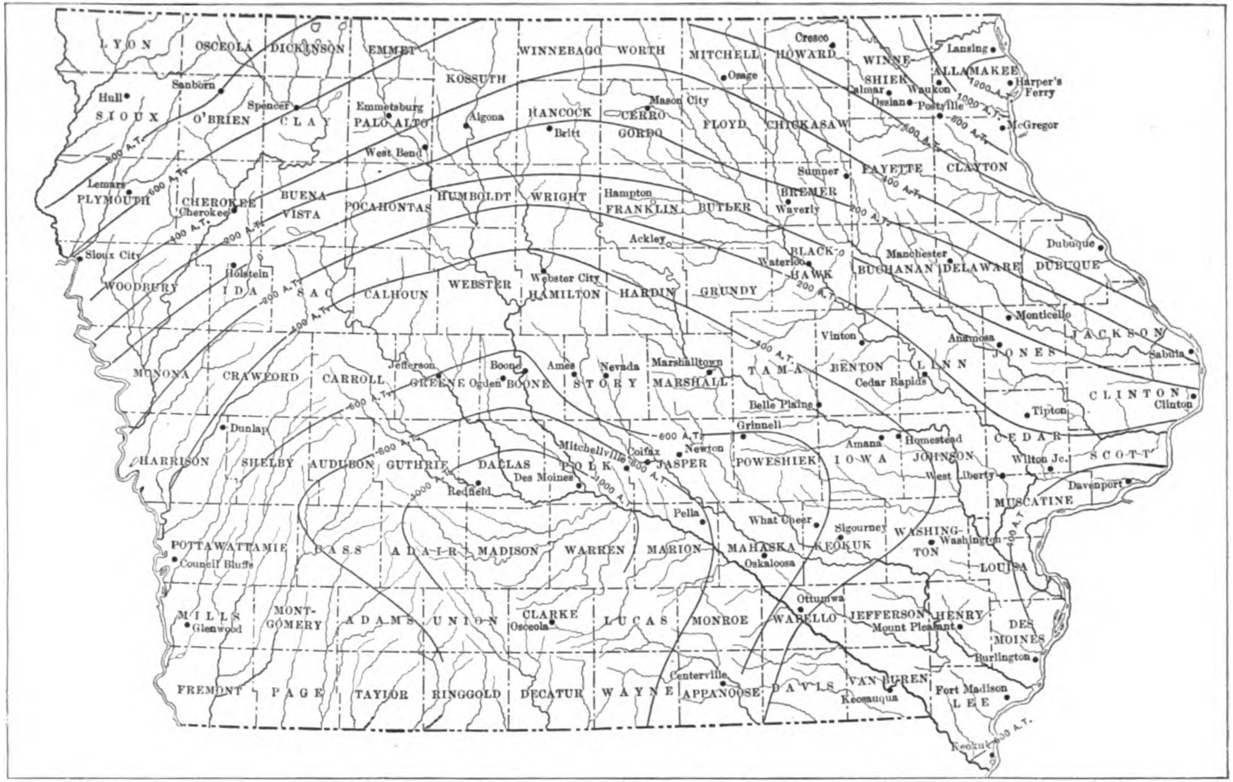
Except a narrow strip along Mississippi River, extending from Scott County southward, which was invaded from the east by the Illinoian ice, the remainder of the State is covered with the Kansan drift sheet, an old drift deeply weathered, and for the most part much cut by streams before the deposition of the surface silt known as "loess." Beneath the Kansan Iowa geologists have recognized still earlier drift, without surface outcrop, known as the "pre-Kansan."

Overlapping one another like the shingles on a roof, these broad sheets of stony clay, with their attendant beds of sand and gravel, largely control the distribution and the quality of the ground water of common wells. The stiff, stony clays of which the drift is chiefly composed are impervious and dry, water being found only in the seams of sand and gravel included within the mass of the drift sheet, and especially in the broad gravel and sand layers by which the successive sheets of drift are often separated, or which often immediately overlie the country rock. Thus the Buchanan gravel, a weathered and thoroughly oxidized deposit of Kansan age, is an important source of supply, even where lying beneath the stony clays of more recent ice invasions.

The drift is so thick and the distance to the various water-bearing layers so great that wells must frequently be sunk to depths of 100 feet or more. Except on special areas such as river plains, where ground water stands near the surface, the windmill is a marked feature of the typical Iowa landscape.

ARTESIAN WATERS.

The artesian field of Iowa is part of the extensive artesian area of the upper Mississippi Valley, which includes also a portion of Missouri, a large part of Illinois, and southern Minnesota and Wisconsin. The catchment area of the field lies for the most part in the two States last mentioned. From this gathering ground a succession of beds which supply all the requisite conditions for artesian wells slope southward. The series consists of many broad sheets of limestones, sometimes cavernous, of impervious shales, and of close-textured to porous sandstones, whose total thickness, as found by adding together the maximum thicknesses of the different formations, amounts to 6,000 feet. These strata, which include representatives of nearly all the stages of the Paleozoic system, and in western Iowa of some of the Mesozoic, rest on a floor of quartzites and schists of Algonkian age. In northern Iowa the strata also dip from the eastern and western boundaries of the State toward a median line, forming a shallow trough or syncline, whose axis lies in about the longitude of the upper Des Moines River. In southern Iowa the western limb of this syncline is depressed, and under the southwestern counties the rock sheets lie more nearly



ARTESIAN LOCALITIES IN IOWA.

The lines show the elevation of the summit of the St. Peter sandstone above sea level.

level. In southeastern Iowa the lower beds rise in a low dome now covered and concealed beneath later formations.

So exceedingly gentle are the dips of these strata that the catchment area is of great width, and the supply of the artesian reservoir correspondingly ample. Of perhaps still more importance is the consequence that even the basal water-bearing beds are within drilling distance over about four-fifths of the State. So far as known, their continuity is not interrupted by any fault or break barring the way of their percolating waters or presenting lines of leakage.

Cambrian rocks.—The lower division of the Cambrian may be called the St. Croix or basal sandstone. It rests directly on the Algonkian floor. It is at least 1,100 feet thick in the vicinity of the Mississippi River, but thins rapidly as it rises on the western side of the central syncline. All its pervious strata are water bearing, except where its summit lies above the ground-water surface along the Wisconsin border. Beyond the counties bordering the Mississippi in northeastern Iowa the nearly static waters of this deep reservoir are likely to be heavily mineralized. Thus at Cedar Rapids in a well that reached the Algonkian quartzite at 1,417 feet below sea level, the basal sandstone waters were so salty and so corrosive to the iron casing that the boring was plugged to shut off all water below that of the Jordan.

The most important water-bearing bed of the Iowa field is the Jordan sandstone, a light-colored, smooth-grained rock, from 100 to 200 feet thick. It is to this water-bearing stratum that drillers are usually encouraged to go, and it is here that they are often also urged to stop. The Jordan is separated by impervious shales and shaly dolomites, called the St. Lawrence, from the basal sandstone.

Ordovician, Silurian, and Devonian rocks.—At the base of the Ordovician is the Oneota (Lower Magnesian), a dolomitic formation, which may be divided into an upper and a lower division, separated by a bed of sandstone equivalent to the New Richmond of Wisconsin. With a thickness of from 300 to 600 feet, it appears to underlie the entire State, everywhere showing the perfect and complete dolomitization and admixture with arenaceous material characteristic of its outcrop. The flow of an artesian well is often notably increased as the drill penetrates this creviced and porous formation with its included sandy layers.

The St. Peter is a remarkably persistent formation whose normal thickness is about 100 feet. It is a bed of incoherent quartz sand, which, because of its freedom from clays and cementing material and because of the phenomenal roundness of its grains, is an exceptionally important water horizon. So distinct are its grains from those of any sandstone above it that the St. Peter is easily recognized by the experienced well driller as well as by the geologist. In northern Iowa,

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[illegible]ll. U. S. Geol. Survey No.

[illegible]1, by N. H. Darton: Water- [illegible]. 39–41.

[illegible]urvey, vol. 6, 1897.

[illegible]ol. Survey, 1904, p. 996.

even as far west as Cherokee, it yields fair supplies of water derived from its outcrops in Minnesota.

Above the St. Peter is the Galena-Trenton, a body of limestone underlying considerable areas within the State. The Galena-Trenton is shaly at its base, and in places thoroughly dolomitized. The dolomitic phase, being porous and often creviced, occasionally yields artesian water, as at Davenport, the water apparently being derived from the underlying sandstone.

The Ordovician series includes as its highest member the Maquoketa shale, which has a maximum thickness of 275 feet, and which, in eastern Iowa at least, effectively seals the formations beneath it. Where it lies near the surface and the Silurian (Niagara) limestone forms the country rock, it gives a water-tight floor, immediately above which water may often be obtained by ordinary wells in quantities sufficient for village supplies.

The Devonian and Silurian rocks are of slight importance except in southeastern Iowa, where the latter become arenaceous and yield a bountiful supply at Keokuk and Fort Madison.

Carboniferous rocks.—The importance of the Carboniferous system as a source of water supply is in part due to its wide extent west of Iowa River. Despite its great thickness—the lower or Mississippian division measuring 670 feet and the upper or Pennsylvanian division (Coal Measures) reaching a thickness of 1,060 feet—the permeable strata of the series are neither thick nor persistent. A number of flowing wells are, however, supplied from it, although their waters are often heavily mineralized and their discharge slight. The well-known medicinal wells of Colfax furnish a typical example. In wells which reach the deep-lying beds beneath the Carboniferous, these upper waters, often impregnated with the sulphates of lime, soda, and magnesia, are not always effectively cased off.

Dakota sandstone.—The Dakota sandstone, which is a source of some importance in northwestern Iowa, is cut off from the great Dakota field, where it carries an enormous volume of water under high head, by the mass of Sioux quartzite of southeastern South Dakota. In Iowa its water is under little head, and so far as tested is of poor quality.

Summary.—Successful artesian wells have been drilled in all parts of the State except on the high divides in southwestern Iowa, where the water-bearing rocks reach their greatest depth below the surface. More than 150 artesian wells—not counting those in glacial drift, which are numbered high in the hundreds—have already been drilled at an expenditure estimated at not less than $500,000. The water supply of some of the larger cities of the State—such as Dubuque, Cedar Rapids, Clinton, and Boone—is drawn in considerable part from artesian wells, but is supplemented from other sources. In the cities the larger number of artesian wells are of private ownership, having been sunk by various manufacturing companies, such as packing establishments, breweries and bottling works, glucose works, and ice factories. In the number of artesian wells, Davenport heads the list with 14 or more. For smaller towns artesian water forms an ideal supply, and about 30 of such towns within the State have already availed themselves of it. Pure, unpolluted artesian waters are provided for a number of the State institutions, including the State College of Agriculture and Mechanic Arts, the two penitentiaries, two hospitals for the insane, and three of the minor institutions.

MINERAL SPRINGS.

Six of the springs of Iowa reported sales of their water for table or medicinal uses in 1902. They are as follows:

Boone Mineral Well, Boone, Boone County.
Colfax Mineral Spring, Colfax, Jasper County.
Fry's Colfax Mineral Springs, Colfax, Jasper County.
Lake View Medical Spring, Lake View, Sac County.
Ottumwa Mineral Springs, East Ottumwa, Wapello County.
White Sulphur Spring, near Davenport, Scott County.

The sales reached an aggregate of 152,050 gallons valued at $14,655.[a]

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 161-163.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 39-41.

Artesian wells of Iowa, by W. H. Norton: Iowa Geol. Survey, vol. 6, 1897.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

MINNESOTA.

By C. W. Hall.

TOPOGRAPHY.

The topographic features of Minnesota are simple, and its relief is low. The highest point of the State—the Misquah Hills in the northeastern corner—is only 2,230 feet in altitude. The lowest point is the shore of Lake Superior at 602 feet. The average elevation is very close to 1,200 feet, since there are 42,390 square miles below and 41,897 square miles above the 1,200-foot level.

WATER RESOURCES.

GENERAL CONDITIONS.

The northeastern portion of the State seems so thoroughly well watered by streams, lakes, and springs that thus far there has been no strong demand for artesian water, and indeed the crystalline rocks lying immediately beneath the glacial drift offer an effectual bar to artesian boring. In the central portion of the State there is an occasional basin in which artesian waters gather and in which there are wells of moderate depth. In these parts of the State much of the surface is too high to obtain flowing water, and is so high that only occasionally can supplies be obtained by pumping. Thus the southeastern and northwestern portions of the State are the only areas which may be regarded as artesian basins in any broad sense of that term.

Exploration for water in Minnesota during the last twenty-five years has shown that artesian waters are derived from a wide range of geological formations, which are grouped according to geologic age into Eo-Paleozoic, Cretaceous, and Glacial drift. There are few areas within the State where waters are not obtainable from at least one of these three groups, if they be obtained at all.

WATER-BEARING STRATA.

There are no water-bearing strata below the Paleozoic. Within the Cambrian and Ordovician rocks, which stretch in a widening belt from Duluth southward to the Iowa line, is a succession of sandstones alternating with shales, dolomites, and dolomitic limestones that yield copious supplies of artesian waters. Comparatively little exploration has been done within this area from Duluth southward to Hinckley, the rocks being too thin and too high above the sea; but from Hinckley to the Iowa line scores of wells have been sunk, which, with very few exceptions, yield a supply of water.

Cambrian.—This series of dolomites, shales, and sandstones varies considerably, as shown by many exposures in the upper Mississippi region. In the St. Croix region is a series to which Dr. C. P. Berkey has given the name Basal sandstone.[a] At the base of this series is a persistent sandstone, attaining a thickness of 1,000 feet at Minneapolis and gradually thinning out in all directions as though beneath this point was the deepest part of a great basin of deposition. So frequently has this bottommost sandstone layer been reached in artesian well boring, that its characters and those of the overlying rocks are thought to be pretty definitely established.

Above this sandstone is a bed of shales and dolomites of varying thickness and texture, which is called locally the St. Lawrence formation. Upon it rests another sandstone series called the Jordan, which locally attains a thickness of 116 feet. This is remarkably porous and is strongly water bearing, yet it is made up of unusually well-rounded and symmetrical grains, varying in coarseness from one-sixteenth of an inch down to granules of extreme fineness.

Ordovician.—Resting upon the Jordan sandstone is the Oneota formation, the most massive and uniform as well as the thickest bed of dolomite within the State. While the Oneota formation in many places is very porous through its dolomitization, it nowhere carries water sufficient to serve as a source of water supply.

Above the Oneota is a layer of sandstone called the New Richmond sandstone. Although this is a very thin layer, nowhere exceeding 20 feet in thickness and in places completely lost sight of by well borers, yet in a few localities it has become the source of a generous water supply. Upon this New Richmond sandstone, which appears to be the basal conglomerate of the Canadian series of the upper Mississippi Valley, rests a dolomite of somewhat unique characters, which for Minnesota has been named the Shakopee. This is of varying thickness and everywhere thoroughly dolomitized. It represents a formation much altered from its original condition. That it once was much thicker than at the present time there is every reason to believe. It sometimes carries small lenticular beds of sandstone, which in certain portions of the State appear as quite conspicuous features in the formation. Elsewhere their absence is a marked characteristic.

Resting upon the Shakopee with some unconformity, evidenced in part by the varying thickness of the Shakopee beneath, is a persistent sandstone called the St. Peter. This sandstone at Minneapolis and

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[a] Berkey, C. P., Geology of the St. Croix Dalles; Am. Geol., vol. 20, 1897, p. 372.

St. Paul is over 160 feet in thickness. Southward it thins to 75 or 80 feet, while at other points it becomes thicker. According to measurements in river valleys and artesian well borings its thickness is variable. This is an unusually strong water-bearing formation, and is utilized wherever it occurs as a source of water. To the north of Minneapolis, where the overlying rocks are removed and the St. Peter itself thinned by erosion, it yields water at varying depths, pumped by windmills for the use of the farm and the truck garden. The last of the Ordovician series in this part of the State is the Trenton-Galena limestone. This has been so eroded by glacial wear that in places it is not more than 10 or 15 feet in thickness, but elsewhere, where protected from erosion, it attains a thickness of 200 or 300 feet. This rock contains no water, but when present serves as an effective cap in confining the waters of the underlying formations.

Cretaceous.—Less is known of the Cretaceous than of any series represented in the State. According to the records of wells, Cretaceous rocks come in from the Dakotas, where well-defined Cretaceous beds occur, and stretch over the divide of crystalline rocks and, in probably continuous beds of sandstones and shales, reach more than half across the State. Yet many portions of Minnesota, even in its western half, show no evidence of the existence of Cretaceous rocks between the glacial drift and the underlying pre-Cambrian rocks. The thickness of the Cretaceous varies and its altitude above the sea is far from uniform. The freedom with which water is obtained from this formation is a valuable factor.

Glacial drift.—This deposit is a remarkably persistent covering for all the older formations. In southeastern Minnesota for a few thousand square miles it is absent. Here the pre-Paleozoic rocks stand out at the surface as the prominent bed rock of the region. This area, named the driftless area by Chamberlin and Salisbury, is a part of the physiographic region embracing southwestern Wisconsin, northwestern Illinois, and northeastern Iowa. The glacial drift nearly everywhere carries water, the places where a sufficient supply can not be found being very few indeed. In thickness the deposits vary from 0 to 300 feet. Mr. Upham thinks that in the western half of the State they can not average more than 75 feet and in the eastern half they are 50 feet thick outside the so-called "driftless area" of the southeastern corner. The glacial drift affords waters through three distinct methods—artesian wells, shallow wells, and springs.

ARTESIAN BASINS.

The artesian basins of Minnesota may be briefly described as the (1) Southeastern artesian basin, (2) Red River Valley basin, and (3) small local basins.

Southeastern artesian basin.—This basin is within the area of the pre-Paleozoic rocks. Each one of the several sandstones in the series will yield water wherever it is present under the necessary conditions. The pre-Paleozoic rocks are in the form of a great arch or dome, the crest of which seems to lie in Rice, Goodhue, and Dakota counties. From this dome the Trenton limestone is worn away and the St. Peter sandstone has been subjected to erosion almost sufficient to sever its southern from its northern area. The lowermost of the sandstone series in this region seems to have a great thickening beneath Minneapolis and St. Paul. A well sunk in Lakewood Cemetery, Minneapolis (elevation 975 feet), disclosed granitic rocks 2,150 feet below the surface. Along the southern border of the State at Winona, Brownsville, and also La Crosse, Wis., granitic rocks were struck at about 525 feet below the level of the Mississippi, where the surface altitude was 625 feet. Since granitic rocks occur at St. Cloud at 1,200

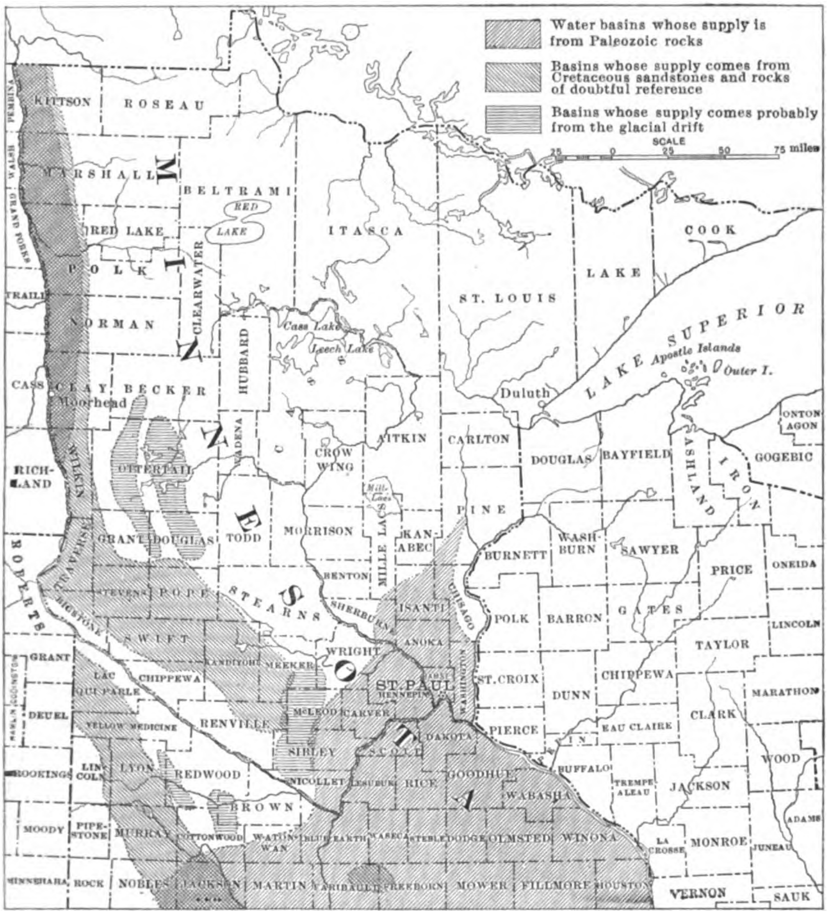

FIG 35.—Artesian basins of Minnesota.

feet above sea level the basin-shaped nature of the bottom of this water-bearing district is clearly seen.

The Southeastern artesian basin lies within the portion of the State first settled. The population within this region is comparatively dense, being, it is estimated, about 100 per square mile. Several towns and many farmers get their principal water supply from artesian sources. It is estimated that 250 wells are now furnishing water within this area.

Red River Valley basin.—In Red River Valley all three of the great water-bearing series are drawn upon for artesian supplies. Comparatively few wells have been sunk to the Paleozoic rocks of northwestern Minnesota, but these few show that the Cambrian and Ordovician are water bearing. With exactly what formation in southeastern Minnesota Red River Valley sandstones can be correlated is impossible to determine with the data now available. The water is of fair quality, abundant quantity, and apparently permanent supply. The Humboldt well, the deep well at Moorhead, and a few others show the nature of the rocks and the quality of the water.

The second water-bearing beds are the Cretaceous sandstones. These are much more strongly developed in the southern end of the district than toward the north, and they show a very apparent tendency to thin out in passing eastward from the Red River and the Bois des Sioux River, which form the boundary between the Dakotas and Minnesota, toward the eastern border of the Red River basin. Indeed it is thought by some that the Dakota sandstone, the the remarkable water-bearing stratum of the James River basin, thins out and disappears before the Red River Valley is reached. Whatever the case, the sandstones which yield the water are uneven in texture, and of varying thickness and mineral composition. The number of wells within Red River basin in Minnesota drawing water from the Cretaceous sandstones is large. Mr. Warren Upham estimates[a] that hundreds exist. Nearly every large farm in the valley has a deep, or artesian, well to supply farm buildings, gardens, and pastures. The surface water and the shallow well water are in many places so alkaline and so disagreeable to the taste that they can not be used successfully.

The third source of artesian waters is in the deeper layers of the glacial drift. Within the great plain of Red River Valley wells in the drift vary from 50 to 150 feet in depth, but in the moranic regions to the east of Lake Agassiz Plain a greater depth is frequently attained. The water from these wells is wholesome and is very generally utilized.

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[a] The Glacial Lake Agassiz: Mon. U. S. Geol. Survey, vol. 25, 1895, p. 523.

SHALLOW WELLS.

By shallow wells is meant those wells from 10 to 100 feet in depth, sunk chiefly for domestic water supply. They are in general use among the farmers, and in the newer towns and villages there are large numbers of them. In older communities they are gradually being displaced by deep borings or, where conditions are favorable, by a supply from lakes or streams of recognized purity. Save in southeastern Minnesota these wells are almost invariably within the glacial drift. The water level in the drift follows so closely the general contour of the surface that there are few wells which do not yield a sufficient supply of wholesome water within shallow depths.

In the southeastern corner, within the so-called driftless area, shallow wells reach into the residual material derived from the alteration of the Paleozoic formations which occur in this portion of the State. The waters here are hard, but as a rule clear and wholesome. The water level is steadily sinking, so that farmers and others utilizing this supply are obliged to bore their wells deeper than formerly. Old wells must be deepened, and even then their supply is less than in former years. It is the general impression that the large demands for water from underground supplies exceed the inflow from the surrounding catchment areas, and thereby the diminution in quantity becomes a question of serious concern.

SPRINGS.

While springs occur throughout the State, there are certain structural conditions which locally prevent their formation. These are the stretches of modified drift and the glacial lake bottoms extended between the morainic belts characteristic of the topography of the State. There are not less than twelve of these moraines in the State. These belts of gravelly ridges and mounds are the source of supply of wholesome yet, in most areas, hard spring water.

There is no especial mode of occurrence noticeable in the distribution of springs. Their place of appearance depends upon the arrangement of the drift material through which or under which the water makes its way, beds of clay of greater or less extent being usually the determining factor. In the northeast portion of the State the conditions of occurrence are quite simple, since the waters gathered in the shallow glacial drift make their way out through the hollows worn by glaciation. In southeastern Minnesota springs occur along the river valleys and represent the completion of the underground circulation through the pre-Paleozoic rocks. The conditions of occurrence are determined by the depth of the river valley and the composition and texture of the rocks through which or between which the waters flow.

The spring water of northeastern Minnesota seems to be softer than any other water in the State. Waters in southeastern Minnesota are, with scarcely an exception, hard. In the western part of the State the underground circulation is comparatively sluggish throughout the extent of the level tracts of glacial drift, which here carries a large proportion of fragments from calcareous shales and Mesozoic limestones. There are many alkaline springs as well as alkaline wells, and hardness is a universal characteristic of the water in this part of the State.

The following springs reported sales of water in 1902:[a]

Highland Spring, St. Paul, Ramsey County.
Indian Medical Spring, Elk River, Sherburne County.
Inglewood and Glenwood Springs, Minneapolis, Hennepin County.
Mankato Mineral Springs, near Mankato, Blue Earth Connty.
Trio Siloam Springs, Austin, Mower County.

The number of gallons sold is given as 2,217,000. The value was $415,140.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 158–159.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 55–57.

Minnesota [well records], by C. W. Hall and J. E. Todd: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, pp. 441–488.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

WISCONSIN DISTRICT.

By Alfred R. Schultz.

LOCATION AND TOPOGRAPHY.

Area included.—The Wisconsin district lies between Lake Superior and Lake Michigan, extending southward approximately to the parallel 41° 30′, and comprising all of the State of Wisconsin, the Northern Peninsula of Michigan, and that portion of Illinois north of the Carboniferous deposits.

Topography.—In general the area is a broad plain, dipping toward the south. Portions of the area are rugged and rocky and broken by hills, which in the western part of Michigan rise to a height of 2,000 feet. North of a central elevation, which ranges between 1,500 and 2,000 feet, the remnants of a mass uplifted in early geologic times, there is an abrupt declivity which reaches to within a few miles of the shore of Lake Superior, 622 feet above sea level. Across the entire northern portion of the area the divide is generally close to Lake Superior. It is lowest in the eastern half, where the Paleozoic rocks form the crest. South of the central elevation is a long slope, which in the southern part of the area is approximately 500 feet above sea level.

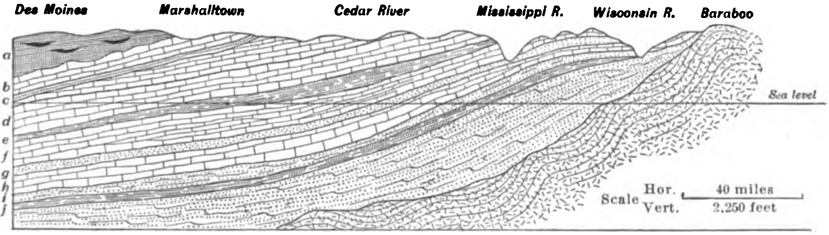

FIG. 36.—Geologic section from Baraboo, Wis., to Des Moines, Iowa. After Norton. *a*, Des Moines; *b*, Mississippian; *c*, Kinderhook; *d*, Devonian-Silurian; *e*, Hudson beds; *f*, Galena-Trenton; *g*, St. Peter; *h*, Oneota; *i-j*, St. Croix, including Jordan, St. Lawrence, and Basal sandstone.

The central upheaval, together with two minor transverse swells, determined the chief drainage systems of the area and in a general way govern the circulation of the underground waters.

Among the minor topographic features are the elevations due to the Baraboo and Wausau quartzites, the Penokee-Gogebic and Marquette iron ranges in Michigan, and the sawtooth ridges of Keweenawan rock in the northwestern part of the district, all of which have affected the drainage and underground circulation. Extending from Green Bay, Wis., diagonally across the area to Rock Island, Ill., is a valley excavated in the soft, easily eroded Cincinnati shale. Its eastern boundary is a steep slope, composed of the resistant Niagara limestone. This valley is one of the most important of the district, many flowing wells being found within its borders. North of Green Bay the rivers, for the most part, cut directly across the underlying shale, but well borings show that the drift here is much deeper than over the Niagara limestone to the east, indicating the continuation of the ancient valley.

GEOLOGY.

Pre-Cambrian rocks.—The elevated central region of Wisconsin consists of pre-Cambrian granites, syenites, and schists, all having a very low crystalline texture and porosity.

North of the crystalline area are the Huronian deposits which form the Penokee-Gogebic iron range with its steep dip to the north, while on the northeast is the trough of the Marquette iron range. Rocks of the same age lie on the east, southeast, and on the southwest of the pre-Cambrian elevation, while small isolated outliers are found scattered over south-central Wisconsin.

The Keweenawan series, which overlies the Huronian, is confined to the northwestern portion of the area lying north of the Huronian of the Penokee-Gogebic iron range. The Keweenawan series extends from the most northern point of Keweenawan Point in a southwesterly direction across the district to St. Croix Falls, where it passes into Minnesota. The rocks lie in a synclinal trough whose axis bears northeast and southwest. In the northern half of the formation only the eastern portion of the trough remains, while the western portion probably lies beneath the surface of Lake Superior. The rocks consist of basic and acidic lavas, conglomerates, and sandstones, three-fourths of which are igneous. The closing of the Keweenawan age also marks the end of volcanic activity within the area.

Potsdam sandstone.—Nearly surrounding these pre-Cambrian rocks, which carry very little water, is the Potsdam sandstone, which rests unconformably and horizontally upon the former. North of the crystalline rocks is a belt of sandstone of varying width bordering Lake Superior.

On the south the same formation extends in a crescent around the crystalline area, with its northeast prong joining the Lake Superior belt near Marquette, Mich., and its northwestern prong passing into Minnesota near St. Croix Falls, Wis.

The sandstone adjacent to Lake Superior in the western half of the area is of a red and brown color, well cemented and firm. Eastward the color becomes lighter and the eastern portion as well as that on the south is white or yellow, poorly cemented and unconsolidated, often crumbling in the hand, while in some cases it is so hard that it might pass for a quartzite. The formation consists of fine calcareous sand, coarse siliceous sand, shales, marls, and layers of sand highly impregnated with iron oxide, thereby causing the water from some of the horizons to flow forth a blood red. The rock is very porous. Its grains are angular, and in some of the lower layers as coarse as No. 4 shot. The sandstone underlies the entire area to the east and south, dipping east, south, and west on the sides of the central elevation. Its thickness varies from nothing along the crystalline margin to 1,488 feet at Rockford, Ill. At Streator, Ill., it has a total thickness of more than 1,737 feet, showing a rapid increase toward the south.

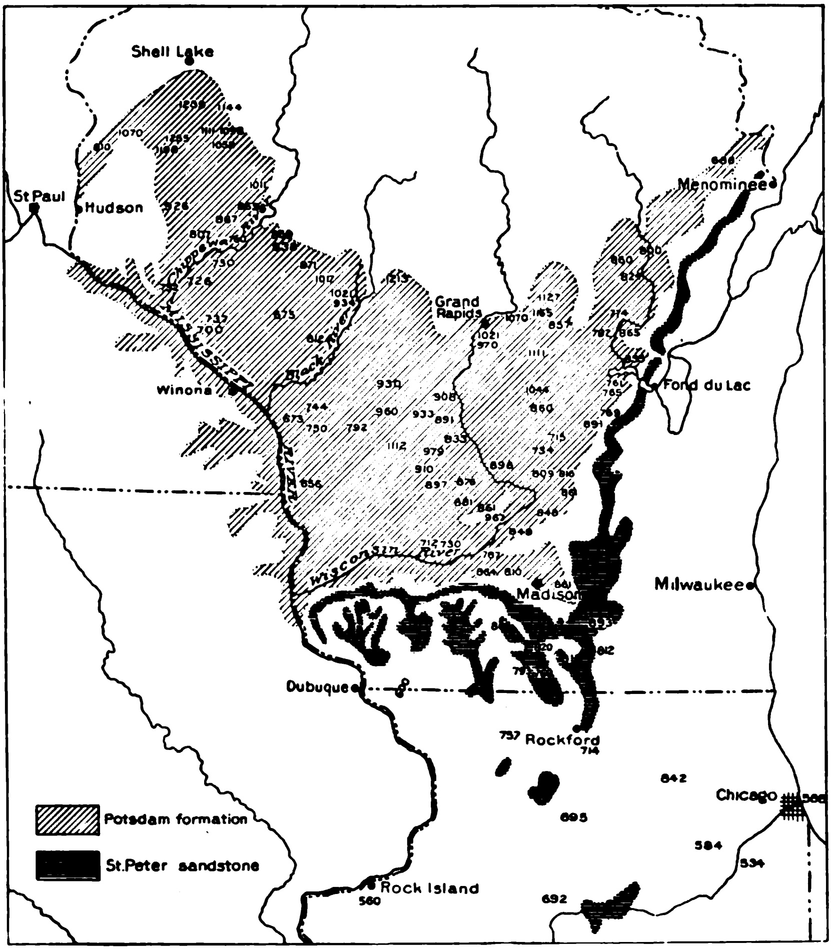

FIG. 37.—Wisconsin outcrop of Potsdam and St. Peter sandstones.

Lower Magnesian limestone.—Fringing the Potsdam sandstone on the south from the eastern part of Michigan to St. Croix River, in Polk County, Wis., is a narrow belt of Lower Magnesian limestone, varying in thickness from 50 to 200 feet. Along St. Croix and Mississippi rivers it caps many of the sandstone ridges. It is a dolomite, with considerable quantities of chert, crystalline quartz, and quartzose sand scattered through it near the middle of the formation.

St. Peter sandstone.—The St. Peter sandstone, which overlies the Lower Magnesian limestone, consists of a soft incoherent rock, of large well-rounded grains of quartz varying in color from white through yellow, pink, to a deep red. The formation is mapped in Michigan with the Lower Magnesian limestone and follows the eastern margin of that formation southward to the Illinois boundary, thence up the Mississippi to Vernon County, where it is all eroded. It reappears in Pierce and St. Croix counties. Isolated portions are also found farther south in Illinois, where erosion once more has brought it to the surface. The northern half of the eastern margin is considerably thinner, often being pinched out entirely, as shown by well records. The formation has a thickness varying from 0 to 250 feet in portions of Illinois.

Galena-Trenton limestone.—The Galena-Trenton limestone occupies a large surficial area extending from eastern Michigan southwest across the country to the Mississippi River, in Crawford County, Wis., and as far south as the southern boundary of the district. Small isolated patches are found capping the highest hills in Pierce and St. Croix counties in west-central Wisconsin.

The upper portion is a dolomite while the lower is more of a limestone. The various beds of this formation are often separated by shale. The rock contains many cracks and fissures which are partly filled with calcite, pyrite, marcasite, galena, and sphalerite. The combined thickness of the Galena-Trenton varies from 200 to 350 feet.

Cincinnati shale.—Overlying the Galena limestone is a formation composed largely of bluish to greenish shale with occasional thin bands of limestone. This shallow sea deposit is known as the Cincinnati shale and is one of the most impervious strata of the area. These soft shales are easily eroded and seldom exposed. They outcrop in a narrow belt seldom more than a few miles in width and close under the protecting Niagara limestone, extending from eastern Michigan southwestward to Rock Island, Ill., forming for the most part the Green Bay and Rock River basins. Another prong extends southeast from Lee County, Ill., around the Carboniferous deposits to the southern boundary of Ford County. A small area is found also in northwestern Illinois, along the Mississippi River. The thickness of the formation may be placed between 150 and 450 feet.

Niagara limestone.—East of the Cincinnati shale occurs the Niagara limestone, which, in a few places, is separated from the shale by the Clinton iron-ore deposits. The Niagara deposit varies in thickness from 450 to 800 feet and extends from the eastern point of Michigan around the lake on its western shore, passing into Indiana southeast of Chicago. A small area is also found along the Mississippi River north of Rock River, capping many of the mounds in southwestern Wisconsin. The formation has a large surficial extent in the eastern part of the area. It is composed largely of calcium and magnesium carbonates and contains a large number of flints. Some portions are hard and cherty, while others are inclined to be sandy.

Later rocks.—Later deposits of rock within the area are of minor importance and occur over very small areas. In Milwaukee and Ozaukee counties in Wisconsin occur small deposits of the Lower Helderberg limestone, while in Milwaukee and St. Ignace, Mich., and south of Rock Island, Ill., occur remnants of a more extensive Devonian deposit.

Drift.—The entire area was overridden by glaciers, except a small part along Mississippi River, extending from Alma, Wis., eastward to Grand Rapids, thence southward until it crosses the Mississippi again near Savanna, Ill., passing into Iowa. The ice sheet left a heterogeneous deposit of clay, sand, bowlders, etc., of varying thickness, burying and modifying the minor topographic features, and governing to a large extent the drainage and the occurrence of surface water throughout the greater portion of the area.

Lacustrine deposits.—Along the borders of Lakes Michigan and Superior are lacustrine deposits composed of alternating layers of red clay and beach sand. These deposits offer one of the cheapest and most satisfactory means of obtaining water for both farm and city purposes.

WATER SUPPLIES.

From the foregoing brief description of the topography, drainage, and geology of the district it may readily be understood that the source of water supply for the crystalline region, with the exception of some of the sandstone of the Keweenawan epoch and the softer horizons of the Huronian, is restricted chiefly to the overlying bed of drift. This area as a whole has a very poorly developed drainage. The water table in most cases lies near the surface. Deep wells are seldom needed in this sparsely settled region. Cool, soft, and comparatively pure water may easily be obtained from the numerous springs, small streams, ponds, rivers, and lakes. Considerable difficulty, however, has been experienced in various places where a large quantity of water was required some distance from a lake or river; in such places the water-supply problem will take on a more and more serious aspect as the country becomes more thickly settled.

Potsdam sandstone.—The greatest of the rock water horizons of the area, and the one that universally furnishes a large supply of water, is the Potsdam sandstone, which nearly surrounds the crystalline rocks. To the south and east this formation is the great source of the artesian waters found scattered over the district. On the north a few records show that waters from its beds rise considerably above the level of Lake Superior. The impervious interbedded shales of this formation furnish ideal conditions for a good artesian supply at many places within the outcrop area itself. The shales, though not everywhere present, often give rise to several separate horizons of water-bearing rock. Wells of this nature may be found at Sparta, Whitehall, Durand, and numerous other places in Wisconsin. Although the water from this formation does not reach the surface in many places, owing to the topography, it is always abundant, and may be depended upon as a supply for city purposes. On account of the advanced erosion and deep-cut valleys the entire Potsdam area west of Green Bay and north of Wisconsin River does not obtain any artesian water from beyond its own limits. Although water is abundant everywhere the artesian flows of this area are confined to the Mississippi Valley and its deeply eroded tributaries—St. Croix, Chippewa, Trempealeau, La Crosse, Wisconsin, Kickapoo, and Baraboo rivers—while on the east this artesian basin extends to Lake Michigan, and on the south it passes under the Carboniferous deposits. Whether artesian flows may be obtained depends largely upon the elevation above sea level.

Lower Magnesian limestone.—Along the eastern margin several water horizons are found above the Potsdam sandstone. Usually a sufficient supply for domestic use is obtained from the Lower Magnesian limestone, 50 to 100 feet from its top. In a few places this formation gives rise to flowing wells, which in some cases are caused by water from the Potsdam sandstone filling the cracks and fissures of the Lower Magnesian.

St. Peter sandstone.—The second greatest water horizon of the area is the St. Peter sandstone. Although of much less importance than the Potsdam, it furnishes an abundant supply of good water in the eastern and southeastern portions of the district. Northward it becomes of less importance, as it thins out and in many places pinches out entirely. In the southwestern part of the district artesian wells have generally not been obtained, as the rivers cut through well into this formation. However, in these parts the St. Peter sandstone always gives an abundant supply of water for domestic uses.

Galena-Trenton limestone.—The Galena-Trenton limestone, like the Lower Magnesian limestone, yields, in most cases, sufficient water for domestic use. It is seldom necessary to sink the wells more than 100 or 150 feet, and in some cases a sufficient supply for small cities has been obtained at 75 feet. In some localities, notably north of Green Bay, this formation gives rise to flowing wells. In some cases it appears that the water of this formation is obtained from the underlying St. Peter sandstone, the overlying Niagara limestone, etc.

Niagara limestone.—The Niagara limestone, although hard, compact, and in places highly impervious, furnishes a copious supply. Water is usually obtained from fissures, joint planes, or crevices at a depth considerably less than 200 feet. The formation furnishes requisite artesian conditions, and in a great many instances, particularly along the eastern half of its extent, between Manitowoc and Milwaukee, many fine flows are obtained.

Along the eastern margin of the district the artesian flows are confined to the vicinity of Lake Michigan and to a strip on each side of all the valleys. In the Green Bay and Rock River basins are many of the flowing wells of the interior. The rapid weathering of the impervious Cincinnati shale has reduced this part of the area to such a level that artesian waters might rise to the surface.

Lake deposits.—Besides these deeper-seated waters and the waters coming from the lacustrine deposits along the shores of Lake Michigan and Lake Superior, the area is well supplied with shallow underground waters, commonly known as surface water. Surface wells are found by the score all over the drift area and vary in depths from 10 to 80 feet, and in some case, as along the Kettle Range in eastern Wisconsin, reach a depth of 300 to 400 feet. Many of these wells are not free from contamination, and during the last few years many have gone dry. In 1903, however, nearly all the wells formerly dry had a good supply of water. Along some of the larger streams water is obtained from the river-washed sand and gravel by sinking wells from 10 to 40 feet. Many of these are open or drive wells.

SPRINGS.

Along both sides of the Kettle moraine glacial drift is the source of many fine surface springs and also of subterranean springs that feed so many of the small lakes. Other strong springs from the drift are scattered over the district. In the northwestern part of the area these strong springs flow from the drift overlying the trap rock, and in many cases the water gushes forth in a small stream several feet wide and over a foot deep. So strong are some of these that they have been utilized for water power, as at St. Croix Falls, where a 35-horsepower mill is operated by the water from a spring. Springs have their source in the upper surface of the Cincinnati shale along the east ridge of the Green Bay and Rock River valleys or along the contact of the Niagara limestone and the Cincinnati shale. The impervious shale stops the descending waters flowing through the fissured Niagara limestone, and it escapes at the first opportunity, producing innumerable springs, both great and small, along the entire extent of this marked and important contact. Much of the water from this source never comes to the surface near the contact but flows underground through the sand and gravel beneath the red clay and gives rise to some of the fountains found east of Fond du Lac. The other important horizons are confined chiefly to the contact of the Potsdam sandstone and Lower Magnesian limestone and to the contact of the Galena-Trenton limestone and the St. Peter sandstone. In many cases in western Wisconsin springs also arise from various horizons of the Potsdam sandstone.

MINERAL WATERS.

Along the eastern margin a considerable number of strong springs flow from the Niagara limestone, of which the most noted are the famous Waukesha Springs, whose waters have long been on the market. Although considerable water is being bottled, this industry is still in its infancy and waiting for development. At present there are innumerable springs moderately charged with mineral matter and well adapted for certain medical uses, whose waters have never been analyzed. Most of the springs within the area contain a small amount of mineral matter averaging approximately 300 parts per 1,000,000. Other springs of a much higher degree of purity are found, one containing only a little over two grains per gallon, three-fourths of which was in the form of carbonates. Most of the springs thus far have received but little attention outside their use for domestic purposes. In some cases springs have been and are being used for public water supplies, as at Lancaster, Wis., where a spring with a daily capacity of 2,160,000 gallons furnishes the entire city with wholesome water. The deeper seated waters are used chiefly for city water supply and for various manufacturing industries.

In a few cases where the waters have rare medical properties, as at Sheboygan and Prairie du Chien, Wis., the waters have been bottled and placed on the market or used for special treatment at the sanitarium. The amount of mineral matter contained in the well water for the most part is comparatively small, in some cases being as low as 7 grains per gallon and seldom being more than 50 grains per gallon. However, in a few cases the amount exceeds 600 grains per gallon, while at Osceola, on Silver Brook farm, the water from the Potsdam sandstone at a depth of 50 feet contained a total of 993.9 grains per gallon, made up as follows: NaCl, 320.58 grains; $CaCl_2$, 583.1 grains; $MgCl_2$, 18.98 grains; $CaSO_4$, 62.20 grains; iron and aluminum oxides, 2.97 grains, and silica, 6.07 grains. Concerning this water, which has recently been analyzed, J. H. Long writes as follows:

> This water is a very unusual and peculiar one because of the presence of so large an amount of calcium chloride. I do not recall any mineral spring in this country which resembles it in this respect, but some of the so-called bitter springs of Germany have a somewhat analogous nature. The water is too highly charged with mineral matters to be used in quantity as a medical beverage, but in special cases and for a limited time it might be profitably used. Such waters are often used for

baths; in fact, that is their main application, and medical men could suggest the cases in which such a water as this one could be used properly.

There is no doubt that in the future these various fields will be greatly extended and many of the cities now without a system of waterworks will soon draw upon the underground channels for their supply.

A list of the springs which reported sales of mineral water in 1902 is given below:[a]

Allouez Magnesia Springs, Green Bay, Brown County.
Aurelian Spring, Palmyra Springs, Jefferson County.
Bay City Spring, Ashland, Ashland County.
Bethania Mineral Springs, Osceola, Polk County.
Chippewa Spring, Chippewa Falls, Chippewa County.
Darlington Mineral Spring, Darlington, Lafayette County.
Fort Crawford Springs, Prairie du Chien, Crawford County.
Lebens Wasser Mineral Spring, Green Bay, Brown County.
Nee-Ska-Ra Mineral Spring, Wauwatosa, Milwaukee County.
Rainbow Mineral Spring, Wautoma, Waushara County.
Salvator Mineral Spring, Green Bay, Brown County.
Sanitas Fountain, Oshkosh, Winnebago County.
Shealtiel Mineral Spring, Farmington, Waupaca County.
Sheboygan Mineral Spring, Sheboygan, Sheboygan County.
Silver Sand Spring, Milwaukee, Milwaukee County.
Slauson Mineral Spring, Racine, Racine County.
Solon Springs, Upper St. Croix Lake, Douglas County.
St. John Mineral Springs, Green Bay, Brown County.
Waukesha Springs, Waukesha County:
    Acme Spring.
    Almanaris Springs.
    Anderson's Waukesha Spring.
    Arcadian Spring.
    Bethesda Mineral Spring.
    Fountain Spring.
    Henk Mineral Spring.
    Hygeia Spring No. 2.
    Minniska Mineral Spring.
    Siloam Mineral Spring.
    Silurian Mineral Spring.
    Sotarian Spring.
    Waukesha Imperial Spring.
    Waukesha Lithia Spring.
    White Rock Mineral Spring.

The reported sales reached a total of 5,982,948 gallons, with a value of $1,199,473.

PRINCIPAL PUBLICATIONS.

Artesian wells, by T. C. Chamberlin: Wisconsin Geol. Survey, 1873–1879, vol. 1, pp. 689–701, 1883.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 151–157.

Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, pp. 65–66.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, p. 996.

LOWER MICHIGAN.[a]

TOPOGRAPHY.

Lower Michigan is mainly a rolling area, with an elevation ranging generally between 600 and 1,000 feet above sea level. In the southern half of the peninsula the general level is broken by relatively low morainal ridges left by the glaciers which once covered the region. In the northern portion of the State the morainal deposits are much more pronounced, occurring as prominent northeast-southwest ridges, and in places rising to heights of over 1,500 feet. The topographic features are, in fact, due almost entirely in most areas to the accumulation of glacial drift, which may reach a thickness of 800 feet or more, and completely buries the irregularities of the underlying rock.

GEOLOGY.

Leaving out of account the glacial drift which has been mentioned above, and considering only the consolidated rocks, the Lower Peninsula of Michigan is structurally a great oval basin, toward which the rocks dip from all sides. The geographic center is in Gratiot County, about 50 miles north of Lansing. The strata are mainly of Carboniferous age, but a rim of Devonian rocks extends along the shores of Lakes Michigan and Huron from Mason County, on Lake Michigan, to Alpena County, on Lake Huron. Small areas or strips of Devonian rocks occur along the rim of the coal basin, in the extreme southeastern and southwestern portions of the State. A few dolomitic and other beds of Silurian age also occur at the extreme northern tip of the peninsula and along the shores of Lake Erie to the southeast.

The general character of the basin and the outcrop of its beds is shown in fig. 38, while fig. 39 shows a cross section of the basin from west to east.

UNDERGROUND WATER SUPPLIES.

SUPPLIES OF THE DRIFT.

Eastern shore district.—This district embraces the eastward-sloping strip lying between the moraines and the shores of Lakes Huron, St. Clair, and Erie, from Saginaw Bay to the southern limits of the State.

The surface deposits of the region, except in some of the valleys and in the old beaches along the lakes, are predominantly clay. The clays yield no water, but small supplies, which are liable to fail in times of drought, are found in pockets of gravel or sand in the clay, and a water-bearing layer commonly occurs at the contact of the drift with the underlying rock. Near the moraine the water-bearing sands are more numerous, and at least one city, Ypsilanti, obtains its public supply from wells in the drift. The waters in the upper part of the drift are of good quality, but in the lower part they are often charged with salt and other minerals, or with gas derived from the underlying rocks from which the waters come. Some of the wells flow. In the stream and other gravels and sands of the valleys and in the sandy

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[a] Compiled mainly from report by A. C. Lane on Water Resources of the Lower Peninsula of Michigan, Water-Supply and Irrigation Paper U. S. Geol. Survey No. 30, 1899. For facts relating to the Upper Peninsula of Michigan, see the description of the Wisconsin district, pp. 233 to 241.

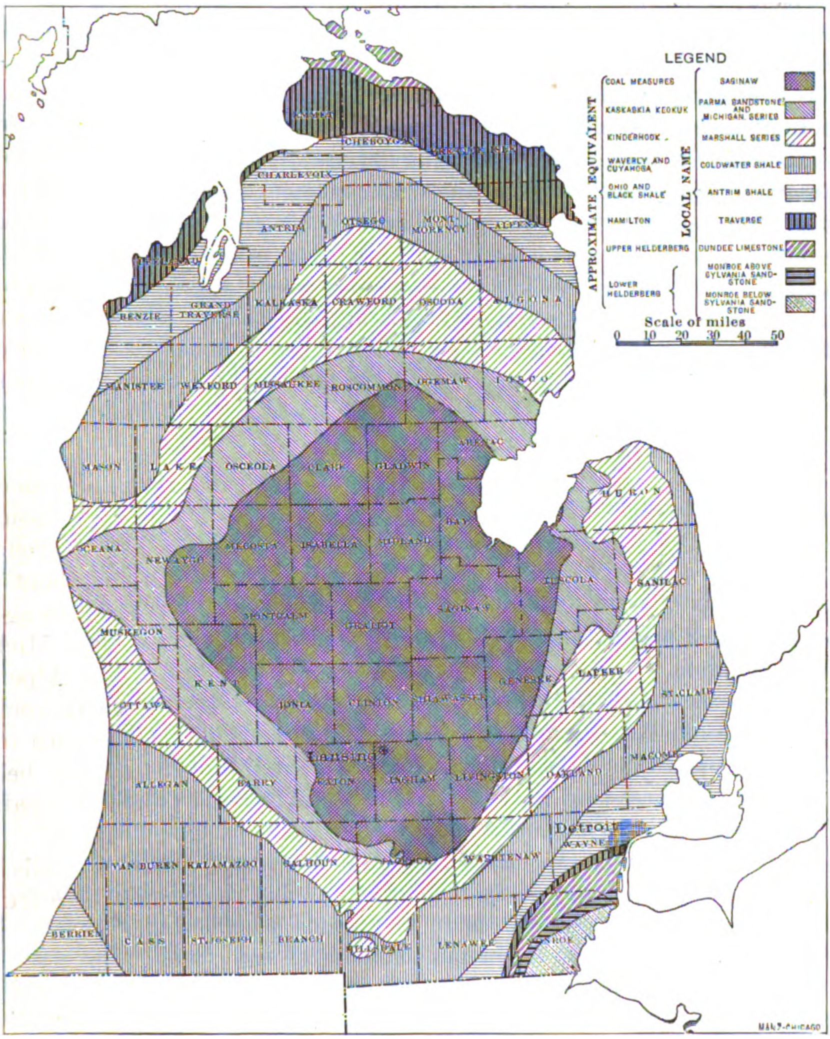

FIG. 38.—Geologic sketch map of lower Michigan.

beaches bordering the lakes good waters are often obtained by shallow wells, but the wells are liable to fail in especially dry seasons.

Saginaw Valley district.—This district includes the drainage basin of Saginaw River and portions of adjacent regions. The surface is flat, the streams generally flowing in shallow valleys. It is covered with clayey drift or hardpan, or with clays deposited in a glacial lake, the deposits averaging from 80 to 100 feet. Sand ridges occur near the lake.

The sand ridges carry water in moderate amount and subject to contamination. Sands and quicksands within the clay frequently yield somewhat hard water, which may even flow. The wells are easily clogged. Water equally good and with a greater head can be obtained by drilling into the underlying sandstones. Some of the drift wells carry calcium sulphate derived from gypsum in the drift, and gas is not uncommon.

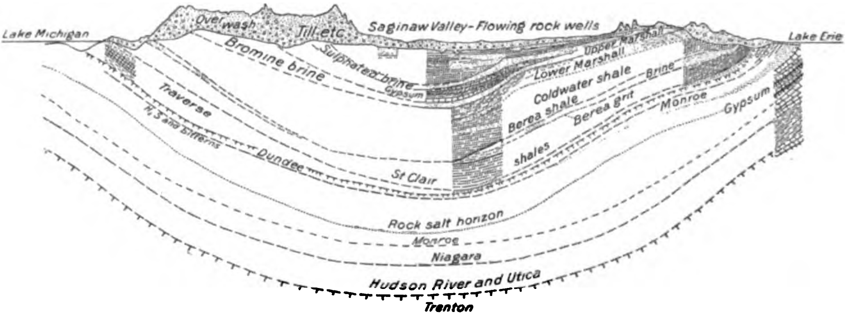

FIG. 39.—Section across lower Michigan.

Northeastern shore district.—This area embraces the drainage area of the Thunder Bay River and a few small streams emptying into the lake in its vicinity. To the southwest lies a high moraine containing some of the highest land in the State. The surface consists of a series of morainal ridges with intervening tracts covered by sand. Water can be obtained from this sand, though it frequently lies at a considerable depth. Springs emerge where the clay layers are cut by streams. Deep wells in the drift find sands with water, which will sometimes rise to the surface from beneath till and clays. The water is quite hard, but is otherwise generally excellent. It is hardly suitable for use in boilers.

Western shore district.—This district lies along the northwest and west coast of the peninsula, and extends inland far enough to include a portion of the high morainal ridges. The surface is drift, the rocks frequently lying from 500 to 600 feet below the surface. The drift is generally clayey, but contains many beds of sand, some of which can be reached by driven wells. Sometimes, in the more porous drift, wells must be sunk 300 to 400 feet to obtain water. The waters are seldom saline.

North-central district.—This area includes the upper portions of the drainage basins of Manistee, Muskegon, and Au Sable rivers and adjacent areas. The surface consists mainly of sandy drift, yielding water to shallow driven wells. In the few deep wells that have been sunk, the thickness of the drift is found to be 350 to 500 feet, or more.

Saginaw moraine district.—This area includes the region of the Saginaw moraines in the central part of the State, and southwest of the Saginaw Valley district. The region is one of morainal drift, the deposits being generally from 100 to 500 feet thick. The composition of the drift is very variable, and many water-bearing sands occur. The underlying rock furnishes a reliable source of water, and a few wells have been drilled into it. Wells some times flow in the lower districts.

South-central district.—This district includes the land in the central portion of the State lying south of the Saginaw district. The drift is usually thick. The water conditions are much the same as in the Saginaw district.

ROCK WATERS.

Trenton limestone.—This limestone has been penetrated at Monroe, Wyandotte, Dundee, Blissfield, and Dowagiac. It yields a strong, but impure brine, with traces of oil and gas.

Hudson and Utica shales.—These shales have been penetrated by a few wells drilled to the Trenton limestone. They are similar to the Coldwater and St. Clair shales.

Niagara and Clinton limestones.—These are penetrated only in southeastern Monroe County, southwest of Kalamazoo and north of Frankfort. Water was obtained from these beds at Dundee and Britton, but they are otherwise undeveloped.

Monroe and Salina beds.—These beds are mainly buff marls, dolomites, and rock salt, but at the top there is a persistent sandy bed yielding much water. The waters are mainly brines, but fresh water has been found in one or two horizons near the outcrop.

Dundee limestone.—This is a light limestone full of flint and carries considerable quantities of water charged with salt, hydrogen sulphide, and other minerals, making it the source of some of the most valuable mineral water of the State.

Traverse series.—This series consists of alternations of limestones and shales with an aggregate thickness of 500 feet or more. In the northern part of the State the series yields water freely in some cases, and even in the southern part water is obtained from several of the limestones.

Antrim shales.—These are blue to black shales underlying the Berea grit. They yield neither fresh water nor brines in any amounts.

Berea shale and grit.—Below the Coldwater shales lies about 130 feet of black or chocolate shales, while beneath these in turn is about 60 feet of white to brown sandstone yielding at any considerable depth pure brines with some gas.

Coldwater shales.—These shales are generally fine grained, micaceous, and bluish. They carry little water, but small amounts are obtained from sandy layers in a few wells.

Lower Marshall sandstone.—This formation is about 260 feet in thickness and consists of ferruginous, sandstones, flags, etc., underlying the Upper Marshall sandstone. It yields good water, rather chalybeate.

Napoleon or Upper Marshall sandstone.—This sandstone, which belongs to the Carboniferous system, is rarely less than 50 feet thick, and underlies the drift in a broad belt extending from Saginaw Bay southwest to the southern boundary of the State in Hillsdale County. It yields copious supplies of fresh water through many flowing wells that have been sunk to a depth of about 250 feet through the western part of Huron County to Sebewaing. Wells sunk to greater depths, if the rocks of the Michigan series are not properly cased off, yield salt water. Southwest of Lansing and Mason the water is generally good.

Michigan series.—This series consists of shales, hydraulic limestones, and gypsum beds immediately overlying the Upper Marshall sandstone. The waters are almost universally salt or bitter, and must be carefully cased off in all wells going to a deeper horizon for fresh waters. This series can be traced beneath the drift by the composition of the water. Included in the Michigan series is the Grand Rapids limestone.

Parma sandstone.—The Parma sandstone unconformably overlies the Michigan series and is generally separated from the Marshall by a thin bed of shales, but in places merges with it. The waters of both the sandstone and limestone are generally hard, though in some cases they are pure. They have seldom been used for brines.

Overlying the Parma is a series of shales, sandstones, coal, fine clays, iron ores, etc., yielding much water of a highly mineralized character and frequently of medicinal value. Wells are very numerous throughout the region.

MINERAL SPRINGS.

The following 28 springs reported sales in 1902, amounting to 8,653,690 gallons, with a value of $275,763.[a]

Alma-Bromo Spring, Alma, Gratiot County.
Andrews Magnetic Mineral Springs, St. Louis, Gratiot County.
Bromo-Hygeia Mineral Well, Coldwater, Branch County.
Clementine Spring, Mount Clemens, Macomb County.
Cooper Farm Spring, Birmingham, Oakland County.
Eastman Mineral Springs, Benton Harbor, Berrien County.
El Cajon Mineral Springs, El Cajon Beach, Alpena County.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

Frankfort Springs, Frankfort, Benzie County.
Magnetic Mineral Spring, Spring Lake, Ottawa County.
Midland Mineral Springs, Midland City, Midland County.
Moorman Springs, Ypsilanti, Washtenaw County.
Mount Clemens Sprudel Water, Mount Clemens, Macomb County.
No-che-mo Mineral Spring, Reed City, Osceola County.
Original Mount Clemens Mineral Spring, Mount Clemens, Macomb County.
Pagoda Spring, Mount Clemens, Macomb County.
Plymouth Rock Well, Plymouth, Wayne County.
Ponce de Leon Springs, Paris Township, Kent County.
Premier (formerly Excelsior) Mineral Springs, Benton Harbor, Berrien County.
Prosit Flowing Well, Oak Grove, Flint, Genesee County.
Red Cross Mineral Well, Big Rapids, Mecosta County.
Royal Oak Mineral Springs, Royal Oak, Oakland County.
Salutaris Spring, St. Clair Springs, St. Clair County.
Sanator, formerly Americanus Well, Lansing, Ingham County.
Sterling Spring, Crystal Falls, Iron County.
Victory Springs, Mount Clemens, Macomb County.
Welcome Island Lithia Springs, near Pontiac, Oakland County.
Wurtzel's Mineral Spring, Thomastown, near Frost, Saginaw County.
Zauber Wasser Springs, Hudson, Lenawee County.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 145–150.
Water resources of the Lower Peninsula of Michigan, by A. C. Lane: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 30, 1899.
Lower Michigan mineral waters, by A. C. Lane: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 31, 1889.
Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 51–54.
Michigan [well records], by W. F. Cooper: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 102, pp. 489–512.

ILLINOIS.

By Frank Leverett.

INTRODUCTORY STATEMENT.

This brief discussion of water conditions in Illinois is restricted chiefly to the relative value of the several geologic formations as water-bearers. Several other topics relating to water conditions, namely, rainfall, drainage basins, run-off and regimen of streams, navigation, water power, city, village, and rural water supply, artesian wells, and water analyses have been discussed by the author in some detail in earlier reports of this Survey.[a] A chemical survey of the water supplies of Illinois is the topic of a report of 98 pages by Dr. A. W. Palmer, issued by the University of Illinois in 1897, and a later report of 254 pages by the same author giving the results of several thousand analyses has been issued by the University within the last year.

GEOLOGIC COLUMN.

The rock formations either exposed or within reach of the wells of Illinois extend through the Paleozoic series from the Cambrian to the later part of the Carboniferous, including perhaps the Permian, as indicated in the table on page 249. There is then a wide gap, the next formation being the Cretaceous, which has been found to underlie the Ohio River at Cairo, but is not known to be exposed in the State.[b] On the borders of the Ohio in southern Illinois are deposits of Tertiary age, consisting mainly of clay, micaceous sand, and a ferruginous, pebbly conglomerate. These deposits are probably separated from the Cretaceous by an interval of some consequence, and are known to be separated from the next later formation developed in Illinois, the Pleistocene, by a wide interval. In the table on page 249 the several drift sheets of the Pleistocene are presented because these divisions of the drift are of importance in discussing the water conditions. They should not, however, be given the rank of the divisions in the Paleozoic series. The table begins with the newest formation and extends to the oldest,

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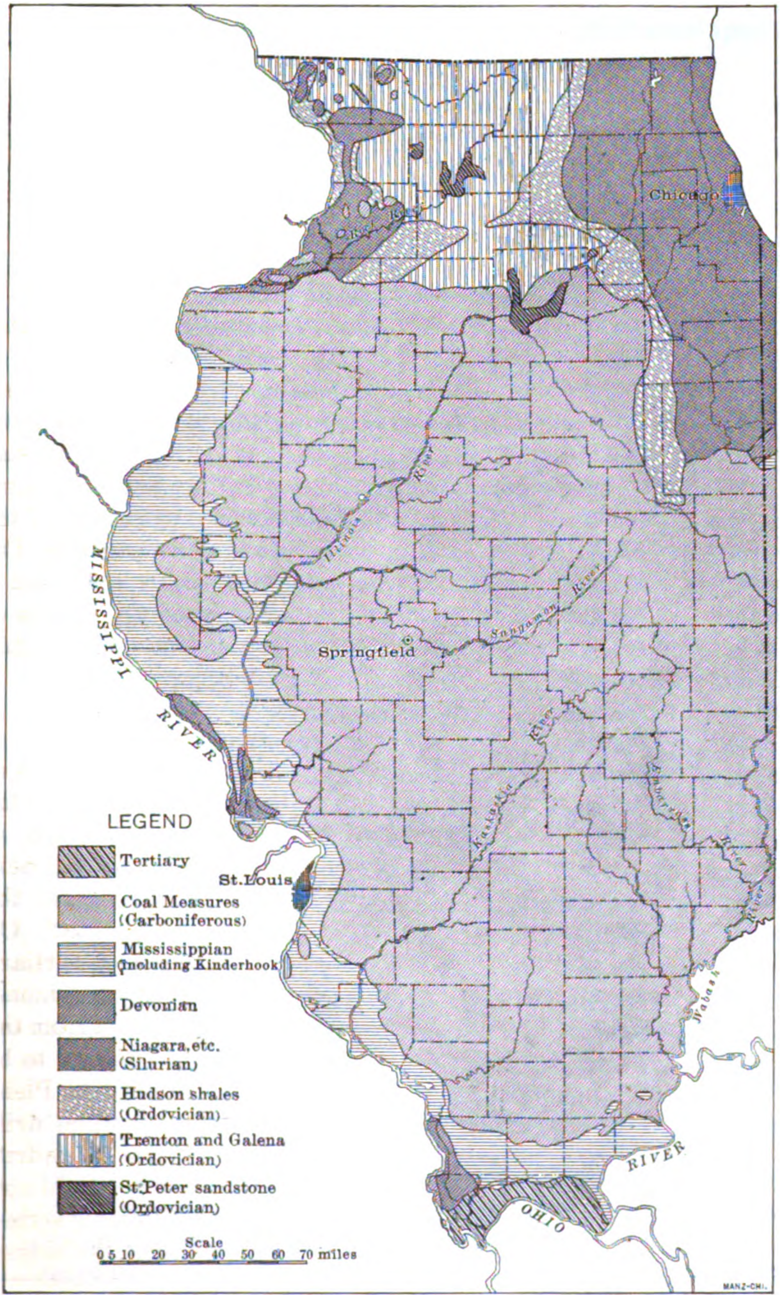
[a] Water resources of Illinois, Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, pp. 695-849. The Illinois Glacial lobe, Mon. U. S. Geol. Survey, vol. 38, 1899, 817 pp.

[b] Nickles, J. M., Report of Illinois Board of World's Fair Commissioners, p. 217, Springfield, 1895. H. W. Rokker, State printer.


Chicago
Springfield
St. Louis
MISSISSIPPI RIVER
Illinois River
Sangamon River
Kaskaskia River
Embarras River
Wabash River
OHIO RIVER
LEGEND
Tertiary
Coal Measures (Carboniferous)
Mississippian (including Kinderhook)
Devonian
Niagara, etc. (Silurian)
Hudson shales (Ordovician)
Trenton and Galena (Ordovician)
St. Peter sandstone (Ordovician)
Scale
0 5 10 20 30 40 50 60 70 miles
MANZ-CHI.

GEOLOGIC SKETCH MAP OF ILLINOIS.

this being the order in which they are met by the drill. The extent of the several formations which lie beneath the Coal Measures has not been tested by a sufficient number of borings to permit even approximate calculations. The figures given are largely conjectural.

Geologic column of Illinois.

Formation.	Extent in State.	Thickness.
	Square miles.	*Feet.*
Wisconsin drift sheet (Pleistocene)	19,000	5-200
Iowan drift sheet and main loess deposit (Pleistocene)	[a] 45,000	5-60
Illinoian drift sheet (Pleistocene)	53,000	10-200
Kansan drift sheet (Pleistocene)	±1,800	±10-100
Pre-Kansan drift sheet? (Pleistocene)	?	?
Tertiary deposits (perhaps of two or more epochs)	700	±10-100
Cretaceous deposits	±10	?
Permian beds?	?	?
Upper Coal Measures (Carboniferous)	19,000	±10-700
Lower Coal Measures (Carboniferous)	36,000	±10-1,000
Conglomerate sandstone (Carboniferous)	±30,000	20-500
Chester group (Carboniferous)	±15,000	10-800
St. Louis group (Carboniferous)	±30,000	20-250
Keokuk group (Carboniferous)	±30,000	100-200
Augusta or Burlington limestone (Carboniferous)	±30,000	25-200
Kinderhook group (Carboniferous)	±30,000	50-330
Black slate (Devonian)	±35,000	10-60
Hamilton limestone (Devonian)	±35,000	10-120
Corniferous limestone (Devonian)	?	5-25
Oriskany sandstone (Devonian)	?	40-200
Niagara group (Silurian)	±45,000	70-400
Hudson River group (Ordovician)	±48,000	40-275
Trenton group (Ordovician)	±55,000	45-450
St. Peter sandstone (Ordovician)	±55,990	40-420
Lower Magnesian limestone (Cambrian)	56,000	±200-1,000
Potsdam sandstone (Cambrian)	56,000	±300-1,000

[a] The loess covered all of Illinois outside the Iowan drift, but was in part taken up by the Wisconsin ice sheet.

The entire thickness of the Paleozoic series of rocks ranges probably from a little more than 2,000 to possibly 6,000 feet. Two borings just outside the State at Burlington, Iowa, and St. Louis, Mo., are reported to have reached pre-Cambrian rocks at 2,400 and 3,800 feet, respectively. So far as known to the writer no wells in the State have reached the bottom of the Paleozoic system, though several have been sunk to depths of more than 3,000 feet. One at Aledo, only a few miles from the Burlington well, terminated in Potsdam sandstone at a depth of 3,115 feet, and one at the Jacksonville waterworks has a depth of 3,028 feet. Probably the deepest boring in the State is one at St. John, Perry County, which reached a depth of 3,750 feet, and may not have entered the Potsdam sandstone.

PRINCIPAL WATER-BEARING FORMATIONS.

Potsdam sandstone.—The Potsdam sandstone is by far the most capacious water-bearing formation in the State. It is a porous rock, and as it is very thick and outcrops over a large area in Wisconsin, the intake is sufficient to give an unlimited supply of water to wells which reach this formation in Illinois. It is, however, within easy reach of wells only in a few counties in the northern and western portions of the State. In the northern part it has been reached by numerous wells as far south as Illinois River and is probably within reach of wells in the portion of the State west of the south-flowing part of the river. On the north border of the State the water is sufficiently fresh in most cases to be suitable for drinking, but upon passing southward it becomes brackish and in many cases unsuitable for domestic use.

St. Peter sandstone.—Next after the Potsdam sandstone should be mentioned the St. Peter sandstone, which is the source of supply for a large number of artesian wells in the northern and western parts of the State. The quality of water obtained from it is usually good, and is adequate to the needs of the smaller cities and towns. But in the larger cities, especially in Chicago, it can scarcely furnish the amount of water needed, and for that reason many wells have been sunk to the Potsdam formation. The porous or water-bearing portion of the formation varies from a thickness of 40 feet up to 150 feet or more.

In several instances wells have obtained good supplies of water from the sandstone beds which appear in the Lower Magnesian formation between the Potsdam and St. Peter sandstone. It is found that this formation is made up more largely of sandstone beds in northern Illinois than in the region of outcrop in Wisconsin, as may be seen by records of wells published in the reports by the author above cited.

Galena limestone.—The Galena limestone is very largely of porous rock, and in the region of outcrop in northern Illinois is a good water-bearer. The drill has shown that parts of it, buried deeply beneath later formations in western Illinois, will yield strong artesian wells, so that it is unnecessary at such points to sink to the St. Peter or lower formations.

Niagara limestone.—The Niagara limestone is another great water-bearer, not only in northern Illinois, where it immediately underlies the drift, but often also when under the cover of other rocks. The water seems in many cases to be traversing the formation in streams or veins, probably along fissures, and the depth to these veins may vary greatly in neighboring wells. The fissures were probably opened widely by atmospheric action before the formation was buried beneath the drift or older rocks. An objectionable feature of many wells obtaining water from the Niagara limestone is the presence of sulphureted hydrogen, formed from the decomposition of pyrites present in the limestone. There are, however, numerous wells in which this is not a pronounced feature, and the water is otherwise palatable and wholesome.

Devonian limestones.—The Devonian limestones are ordinarily poor water-bearers compared with the Niagara limestone, yet, in certain localities, they afford sufficient water to supply local needs. Their outcrop is also much more restricted than that of the Niagara, being confined to small areas in the western and southern parts of the State.

St. Louis limestone.—The limestone formations of earlier Carboniferous age have outcrops over several counties in western and southern Illinois, and, though not great water-bearers, are drawn upon largely where the glacial deposits are either wanting or are too thin to supply the water.

Chester sandstone.—The Chester group of southern Illinois contains sandstones which are generally good water-bearers, but their outcrop is limited and they soon pass to so great a depth as to make drilling to them expensive. The water in the deep-lying beds is also liable to be brackish or unsuitable for domestic use.

"*Conglomerate*" *sandstone.*—The "Conglomerate" sandstone which underlies the Coal Measures in central, eastern, and southern Illinois is not likely to become a valuable source of water for domestic use, for it is a very thin formation in the northern part of its field, and where thick in the southern part is generally buried deeply under Coal Measures. In the latter situation it is usually charged with salt water.

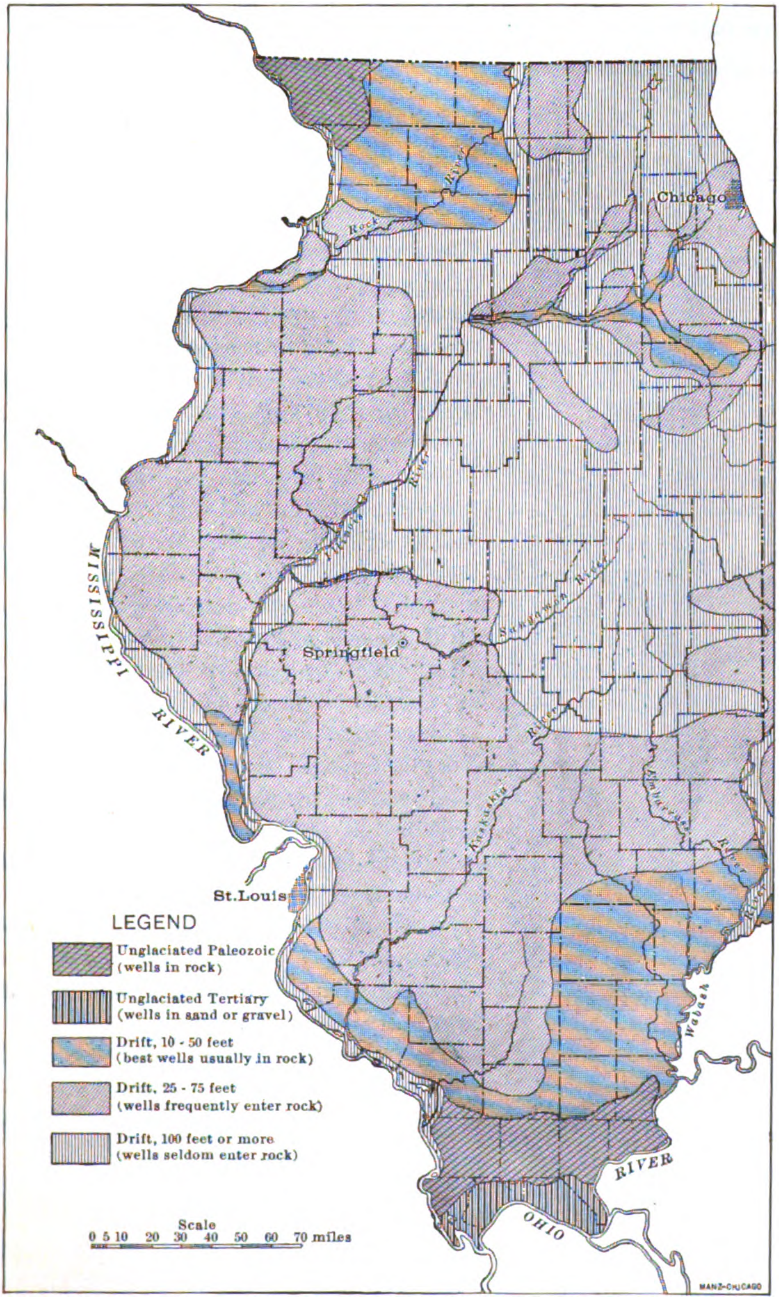
Coal Measures.—The sandstone beds of the Upper and Lower Coal Measures constitute probably half the thickness of the formations, and they are generally permeated with water which, however, is suitable for domestic use only at a few horizons, usually within 200 feet of the surface, for at other horizons and at greater depth there are often either salt or sulphates to render the water objectionable. These formations, however, usually supply the needs of residents in places where the drift cover does not furnish a sufficient amount of water.

Tertiary deposits.—The Tertiary deposits are of limited extent and shallow depth and afford a very unimportant part of the water supplies of the State. In the region where they occur wells are often sunk to the underlying limestone.

Glacial deposits.—The glacial deposits are probably more often drawn upon than all other formations combined, for they are surface formations and the water is reached by wells of moderate depth such as nearly every resident can afford. There are probably more than a half million wells in these deposits. The complexity of the glacial formations, however, is such that in a large part of the glaciated area it is difficult to forecast the results of boring into them. It is estimated that about 70 per cent of the glacial drift is a compact clayey material affording very little water, except by slow seepage. The remaining 30 per cent would, if distributed to the best advantage, be adequate to the needs of residents. But unfortunately there are tracts of considerable extent in which the drift is almost wholly of a clayey constitution, while other tracts have a superabundance of water-bearing material. A somewhat detailed study of these deposits has shown that the distribution of the sand and gravel beds depends to a large degree upon the drainage conditions attending the melting of the ice. In the repeated advances which the ice made into this region the sand and gravel beds distributed by the water from the melting of a given ice sheet were overridden and buried deeply in places by the deposits from a later ice sheet. Then, too, there appear to have been minor oscillations of the ice front in each stage of glaciation by which sand and gravel beds, which had been spread out at the edge of the ice sheet, were covered by clay deposits laid down during the readvance of the ice. In western and southern Illinois the sand and gravel found in the drift seem to have been deposited as the result of these minor fluctuations, for they are distributed in very irregular and limited areas. In central, eastern, and northeastern Illinois there are, in addition to such beds, more extensive ones lying between the main drift sheets. It is also found that throughout the State a large amount of sand and gravel and abundance of water are usually found along the line of pre-Glacial valleys. In the northern part of the State, north from a line running from Rock Island to Watseka, there is a large amount of gravelly and sandy drift at or near the surface. Farther south the surface sand and gravel are generally restricted to the valleys of the main drainage lines. Pl. XVI indicates the relation of the drift to the wells. It shows the areas in which wells are obtained almost wholly from the drift, areas in which drift and rock wells are each used extensively, and areas in which it is generally necessary to go into the rock to obtain water. There are many weak wells within the areas of thick drift, but in the great majority of cases farmers have penetrated to water-bearing beds or veins, which afford an adequate supply.

LOCALITIES FAVORABLE FOR ARTESIAN WELLS.

Artesian wells as here discussed include only wells which overflow, whether from the rock or from the glacial formations. It should be understood, however, that a large number of wells not classed as artesian are under the same hydrostatic pressure as those that flow and the water rises to a similar altitude above sea level.


Chicago
Rock River
Illinois River
Sangamon River
Springfield
Kaskaskia River
Embarrass River
Wabash River
MISSISSIPPI RIVER
St. Louis
OHIO RIVER
LEGEND
Unglaciated Paleozoic (wells in rock)
Unglaciated Tertiary (wells in sand or gravel)
Drift, 10 - 50 feet (best wells usually in rock)
Drift, 25 - 75 feet (wells frequently enter rock)
Drift, 100 feet or more (wells seldom enter rock)
Scale
0 5 10 20 30 40 50 60 70 miles
MANZ-CHICAGO

MAP SHOWING THICKNESS OF DRIFT IN ILLINOIS.

The artesian wells obtained from the several rock formations in northern and western Illinois must generally be situated on ground less than 700 feet above sea level, for it is well established that water will not rise above that height, except in the extreme northern part of the State or in localities where the greater head is obtained from drift formations, which constitute the main source of supply for the wells. In southwestern and southern Illinois the ground must be considerably lower than in northern and western Illinois to obtain a flow. In the latitude of St. Louis, and south from there, the head is generally as low as 500 feet above tide, and flows are obtained only at a few points, there being a less uniform head or hydrostatic pressure than in the northern and western parts of the State. The most favored part of the State for deep artesian wells is that lying north and west of Illinois River. The following section (fig. 40) is along a line from Wisconsin River in western Wisconsin southward to Cap au Grès near the mouth of Illinois River through a region where artesian wells are very successful. It will be observed that northward from Aledo the section shows but one shale bed—the Hudson—and this is wanting north of Galena, but south from Aledo the Kinderhook, Devonian, and Coal Measures shales comprise a considerable portion of the section. It is thought that the intake is not restricted to the outcrop of the sandstone in Wisconsin, but that the limestones and other pervious beds farther south take in a large amount of water.

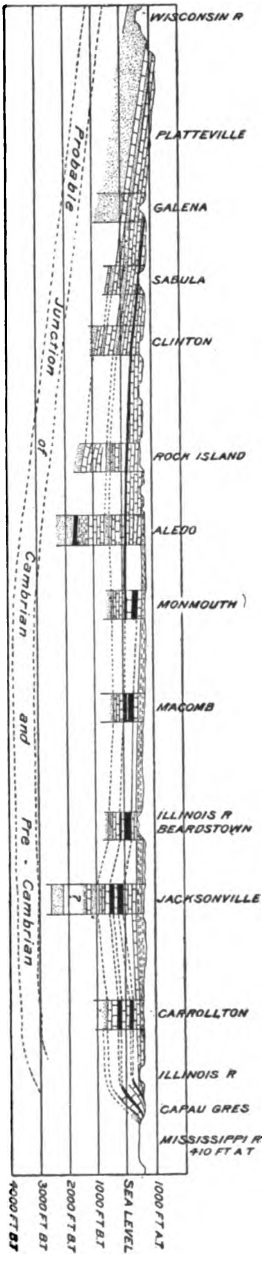


FIG. 40.—Section from the Wisconsin River in western Wisconsin southward to Cap au Grès, near the mouth of Illinois River. The black bands represent shales; other beds are fair to good water bearers.

There are only a few small areas in Illinois in which the drift furnishes flowing wells. These areas are usually on the slopes of moraines, or along valleys in which there is a thick filling of drift. The intake appears to be on the moraines or possibly on outlying gravel plains in the first instance, and on higher ground bordering valleys in the second instance. In these wells, as in those which obtain their supply from the rock, the rise of water, or hydrostatic pressure, is in many cases no greater than in neighboring wells that do not overflow, the overflow being due to the low altitude of the surface. The largest flowing well district is in a basin lying on the north slope of a morainic system in Iroquois County and border portions of adjacent counties in eastern Illinois, and comprises an area of about 500 square miles. There is a smaller district with exceptionally strong flows around Potomac, in northern Vermilion County. Other small districts occur near Plattville, in Kendall County; near Earlville, in northern Lasalle County; near Sycamore, in northern Dekalb County; near Palatine, in northern Cook County, and along Salt Creek Valley, in northern Cook and eastern Dupage County. There are a few flowing wells along the north fork of Chicago River, in northern Cook and southern Lake counties. Flowing wells are also common in low-lying tracts among moraines of Lake, McHenry, and Kane counties. The combined area of all these small districts will probably not greatly exceed that of the Iroquois district (500 square miles). Occasional flowing wells are scattered over the central part of the State, chiefly along river valleys, and there are very few in the western and southern portions in similar situations.

WATERS IN RELATION TO HABITATION.

The census of 1900 gives Illinois a population of 4,821,550, which warrants the assumption of a present population of about 5,000,000. About half of this population derives the supply for drinking and many other domestic uses from surface water, Lake Michigan furnishing water for the 2,000,000 or more people of Chicago, and several other small cities along the lake, and the streams of the State furnishing a supply for about 300,000 people living in the small cities and villages. It is estimated that about a half million people obtain their drinking water from wells of considerable depth. There thus remains about 2,000,000 people who are supplied from wells of shallow depth. A small part of the population, residing principally in the driftless parts of the State, depend entirely upon rain water collected in cisterns, and rain water is used to a small extent in every community throughout the State for drinking water, and is used extensively for other domestic purposes. Spring water is also in use to a very limited extent throughout the State.

The chemical survey of the waters of the State instituted at the University of Illinois in 1895, and conducted by Prof. A. W. Palmer, has called attention to the quality of the water from the several sources in use. Up to the present time about 11,000 sanitary analyses and 500 mineral analyses have been made, representing conditions in 100 of the 102 counties and about 500 cities, villages, and hamlets. From the latest report,[a] covering the period 1897 to 1902, inclusive, the following results of the survey are taken. The rain water in use by the residents is seldom properly filtered and the ordinary cistern filter, "as commonly managed or rather neglected, frequently is almost worse than useless, inasmuch as it soon becomes surcharged with matters which it has removed from some of the water, and then, instead of purifying the water that subsequently passes through, often becomes a source of offense if not of danger."

"In general, water taken from lakes, from streams, or from the ground, when these sources of supply are in their original or natural condition, is perfectly wholesome and unobjectionable, but with increasing population and longer occupancy of the ground the conditions change and contamination becomes inevitable." For this reason Professor Palmer remarks that it would be best for even the people of the smallest towns to use for drinking purposes only the water supplied by one general plant, the sanitary condition of which could and should be thoroughly and periodically investigated by experts acting under the direction of a water commission or the State board of health.

This chemical survey has shown that the normal shallow drift waters contain chlorides, sulphates, carbonates, and silicates of calcium, magnesium, potassium, and sodium, with minute quantities of iron and aluminum compounds, together with considerable quantities of nitrates, but only minute quantities of saline ammonia and albuminoids; organic matters are almost entirely absent; nitrites are frequently present in notable quantity. The normal deep drift waters contain in general the same mineral salts as the shallow waters, but usually the quantity of iron is considerable, and the nitrates are either entirely absent or present in but minute quantity, while free ammonia is abundant and albuminoids are present in considerable quantities. "Oxygen consumed" is high, and the water residue blackens upon being heated, showing that it contains much organic matter. The waters from shallow wells are well aerated and are clear, sparkling, cool, and of agreeable taste; those from the deeper wells contain little or no oxygen, possess in many cases a disagreeable taste, due to the presence of marsh gas, accompanied occasionally by minute quantities of sulphureted hydrogen, and are either turbid or become turbid quickly on exposure to air, owing to the oxidation of the iron carbonate which they contain and the consequent precipitation of insoluble ferric compounds.

"Although these unpleasant characteristics of the deep drift waters give rise to much prejudice and objection to their general use for drink, nevertheless, from the sanitary standpoint they are usually to be preferred to the clear and palatable waters of the shallow wells, since the evidence of numerous analyses shows that they are less subject to pollution with refuse animal matters than are the latter, while the organic matters which they contain are derived from buried vegetable remains and are comparatively harmless.[a]

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[a] Chemical Survey of the Waters of Illinois. Report for the years 1897-1902, by Arthur William Palmer. Published by the University, 1903, 254 pages.

MINERAL SPRINGS.

Though not so abundant as in more rugged areas, springs are nevertheless numerous in Illinois. Those of the drift are probably the most abundant numerically, but the individual springs are generally small, sometimes being mere seeps. Such waters vary in character according to the constitution of the drift, but in general they are hard, and frequently carry considerable iron in solution. In the Coal Measure rocks they are very often highly charged with iron sulphate or carbonate, salt, hydrogen sulphide, etc., while in the limestone the waters are generally very hard. Springs are numerous, and sometimes of considerable size in the limestones and older sandstones, especially along the bluffs of Mississippi River.

A considerable number of the mineral springs are the sites of resorts of more or less importance. Many report sales of water for medicinal or table purposes. The 22 springs reporting to the United States Geological Survey in 1902 are as follows:[b]

Abana Spring, Libertyville, Lake County.
Anna or Cave Mineral Springs, Anna, Union County.
Aqua Vitæ Mineral Springs, near Maquon, Knox County.
Aurora Lithia Spring, Montgomery, Kane County.
Black Hawk Springs, Rock Island, Rock Island County.
Blue Grass Springs, Montgomery, Kane County.
Cumberland Mineral Spring, near Greenup, Cumberland County.
Deer Lick Mineral Spring, Dearfield, Lake County.
Diamond Mineral Spring, Grantfork, Madison County.
Elmhurst Mammoth Spring, Elmhurst, Dupage County.
Glen Flora Mineral Springs, Waukegan, Lake County.
Gravel Springs, near Jacksonville, Morgan County.
Macinac Mineral Spring, Woodford County, near Carlock.
Magnesia Spring, Montgomery, Kane County.
Min-ni-Ni yan Spring, Bristol, Kendall County.
Mokena Mineral Spring, Mokena, Will County.
Original Springs, Okawville, Washington County.
Perry Mineral Springs, Perry Springs, Pike County.
Red Avon Mineral Spring, Avon, Fulton County.
Sanicula Springs, Ottawa, Lasalle County.
Sylvan Dell Spring, Galewood, Cook County.
White Diamond, formerly Spouting Mineral Spring, South Elgin, Kane County.

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[a] Chemical Survey of the Waters of Illinois. Report for the years 1897-1902, by Arthur William Palmer. Published by the University, 1903, pp. 8-9.

[b] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

The aggregate sales of these 22 springs are given as 1,767,955 gallons, with a value of $89,565.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale. Bull. U. S. Geol. Survey No. 32, pp. 142-144.

Preliminary list of deep borings in the United States, pt. 1, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 57, pp. 25-30

Water resources of Illinois, by Frank Leverett: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 695-849.

Wells of Illinois, by Frank Leverett: Mon. U. S. Geol. Survey, vol. 38, pp. 550-787.

Description of the Danville quadrangle, by M. R. Campbell and Frank Leverett: Geol. Atlas U. S., folio 67, U. S. Geol. Survey.

Description of the Chicago district, by W. C. Alden: Geol. Atlas U. S., folio 81, U. S. Geol. Survey.

Description of the Patoka quadrangle, by M. L. Fuller and F. G. Clapp: Geol. Atlas U. S., folio 105, U. S. Geol. Survey.

Geology of Illinois as related to its water supply, by Charles W. Rolfe: Report on Chemical Survey of the Waters of Illinois. University of Illinois, 1903, pp. 41-56.

INDIANA.

By Frank Leverett.

INTRODUCTORY STATEMENT.

This brief discussion of water conditions in Indiana, like that of Illinois, is restricted chiefly to the relative value of the several geologic formations as water bearers. A more detailed discussion of drainage systems, underground waters, mineral springs, and water supplies for cities and villages will be found in a paper[a] by the author which appears in the Eighteenth Annual Report of the United States Geological Survey (pp. 425–559) and a discussion of the wells of Indiana, taken up county by county, in Water Supply and Irrigation papers Nos. 21[b] and 26.[c] The geologic structure of Indiana has been discussed in part or as a whole in several of the reports of the State geological survey, but except the very excellent discussion of mineral waters in the Twenty-sixth and Twenty-seventh Annual Reports, the State reports contain little information concerning water supplies. A paper on the "Natural Gas Field of Indiana," by A. J. Phinney, in the Eleventh Annual Report of the United States Geological Survey (pp 509–742), presents many data concerning water supplies.

GEOLOGIC COLUMN.

The formations exposed in Indiana extend with but slight breaks from the Hudson River group to the Coal Measures. There is then a wide gap, the next formation being of Tertiary (?) age, after which another interval appears between the Tertiary (?) and the glacial formations. The table on page 259 gives the formations penetrated by the drill, beginning with the newest and extending to the oldest. It also includes the formations below the Hudson River group which have been reached by the drill.

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[a] Water resources of Indiana and Ohio.

[b] Wells of northern Indiana.

[c] Wells of southern Indiana.

Generalized section of the rock formations of Indiana.

[Modified from section of A. J. Phinney in the Eleventh Annual Report of the U. S. Geological Survey, pp. 624-625.]

	Thickness.
	Feet.
Recent deposits, alluvium, peat, marl, etc	5–50
Wisconsin drift sheet (Pleistocene)	5–250
Loess, marl loess, white clay, etc. (Pleistocene)	5–50
Illinoian drift sheet (Pleistocene)	5–250
Kansan and pre-Kansan drift sheets (?) (Pleistocene)	(?)
Tertiary (?) deposits (age undetermined)	5–50
Upper Coal Measures (Carboniferous)	50–195
Middle Coal Measures (Carboniferous)	600–888
Lower Coal Measures and Conglomerate (Carboniferous)	60–210
Chester group (Carboniferous)	0–74
St. Louis group (Carboniferous)	0–330
Keokuk group (Carboniferous)	6–106
Knobstone and Waverly (Carboniferous)	42–532
Black shale (Devonian)	70–120
Brown shale (Devonian)	25–47
Hamilton limestone and shale (Devonian)	47
Upper Helderberg (Devonian)	5–65
Schoharie (?) (Devonian)	14–20
Lower Helderberg (Silurian)	25–230
Waterlime (Silurian)	65–150
Niagara group (Silurian)	52–480
Clinton group, limestone and shale (Silurian)	46
Medina (?) (Silurian)	60
Hudson River group (Ordovician)	260–860
Utica shale (Ordovician)	0–300
Trenton group (Ordovician)	486–525
St. Peter (Ordovician)	150–224
Lower Magnesian (Cambrian)	400±
Potsdam sandstone (Cambrian)	323+

PRINCIPAL WATER-BEARING FORMATIONS.

St. Peter sandstone.—The St. Peter sandstone, in the Indiana field, usually is a calcareous, loose-textured rock, saturated with salt water, containing more or less sulphate of magnesia and sulpureted hydrogen. It may, however, be potable in the extreme northwest part of the State.

Trenton limestone.—The porous portion of the Trenton limestone, except in parts of the State where it carries natural gas and oil, is also saturated with salt water, the water taking the place of the gas and oil as the latter become exhausted by pumping.

Hudson beds.—The Hudson group is a very poor water bearer, being composed largely of shale. It is used to a limited extent, however, at its outcrop in the southeastern part of the State to supply water for domestic use.

Clinton and Medina beds.—The Clinton and Medina are comparatively thin formations with very limited areas of outcrop, and are, as a rule, inferior water bearers.

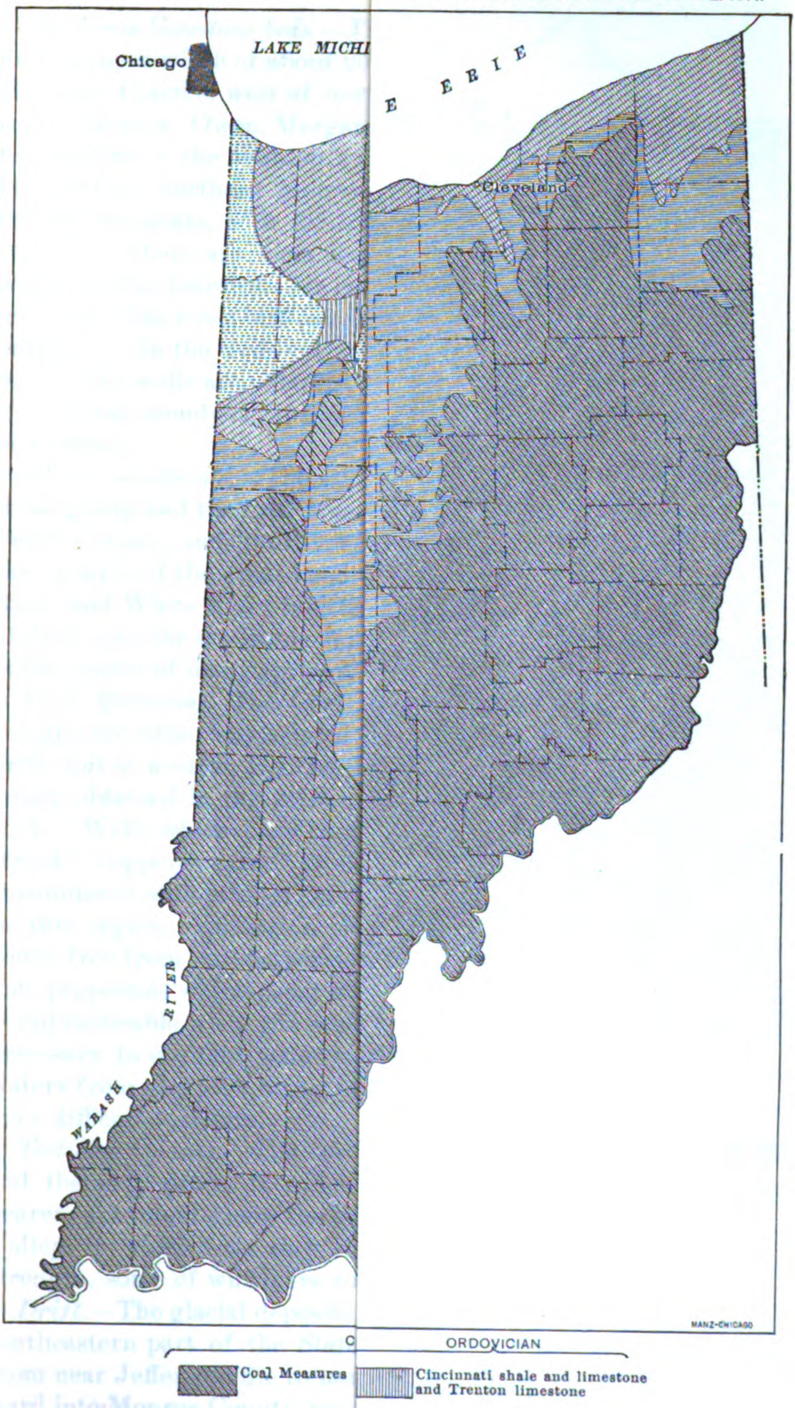
Niagara limestone.—The Niagara group consists largely of a limestone which, as in Illinois, contains a large amount of water, generally palatable and suitable for domestic use. In some cases, as in Illinois, the water is charged with sulphureted hydrogen produced through the decomposition of pyrite included in the limestone. This limestone furnishes probably the most abundant supply of water suitable for domestic use to be found in any single rock formation, since it is struck at moderate depth in much of the eastern part of the State. When it passes under the cover of later formations and sinks to considerable depths the water becomes brackish and is unsuitable for domestic use.

Waterlime and Lower Helderberg limestones.—The limestone formations above the Niagara to the base of the Devonian shale afford good supplies of water in the region of outcrop, water being generally struck in veins or fissures, as in the Niagara limestone. The outcrops are, however, comparatively few, since these formations are ordinarily buried under very heavy deposits of drift. Their value as water bearers is found chiefly along the Wabash Valley above Delphi and in the southern part of the State, where the drift is thin or wanting.

Devonian shale.—The Devonian shale which underlies heavy deposits of drift in the northern part of the State and also a narrow strip leading west of north from Ohio River at New Albany to the Tippecanoe near Monon is perhaps the poorest water-bearer in the State, but it is so generally deeply covered by water-bearing beds of drift that there is little need of penetrating it.

Waverly shale.—The Waverly shale, which is found on the north border of the State, like the Devonian shale, is a very poor water-bearer, and like it, too, is concealed deeply beneath water-bearing beds of drift.

Knobstone formation.—The Knobstone formation from the central part of the State southward constitutes the knobs or most hilly tracts of southern Indiana, and includes some sandstones as well as shales. It is covered by drift north from northern Brown County, and the drift-covered portion is not drawn upon for wells to any notable degree. The driftless portion of this formation is only sparsely settled and the residents depend to a large degree upon springs which issue from the sandstone beds along the valley slopes. The water is ordinarily fresh and much softer than that obtained from neighboring limestone formations.


Chicago
LAKE MICHI
ERIE
Cleveland
WABASH RIVER
MANZ-CHICAGO
C
ORDOVICIAN
Coal Measures
Cincinnati shale and limestone and Trenton limestone

St. Louis limestone beds.—The St. Louis limestone belt occupies in its outcrop a width of about 20 miles, and extends from Ohio River in Harrison County, west of north through Washington, Orange, Lawrence, Monroe, Owen, Morgan, Putnam, and Montgomery counties to the borders of the Wabash Valley above Attica. It is unglaciated as far north as northern Monroe County, and furnishes the sole supply for the residents, with the exception of the rain water collected in cisterns. There are some localities in which the expense of sinking wells into the limestone far enough to strike water is so great that cistern water has come into use for drinking as well as for other domestic purposes. In the drift-covered portion of this limestone belt a large part of the wells are obtained without entering the limestone, though its several members appear to be good water bearers wherever penetrated.

Chester sandstone.—The sandstones which come in between the limestone group and the Coal Measures form a narrow strip running from Perry County, on Ohio River, west of north to the Wabash Valley at the vicinity of the great bend near Attica. The region between Ohio River and White River is either driftless or carries only a thin deposit of drift, and the sandstone supplies water at moderate depths and also is the source of many springs, usually of fresh water.

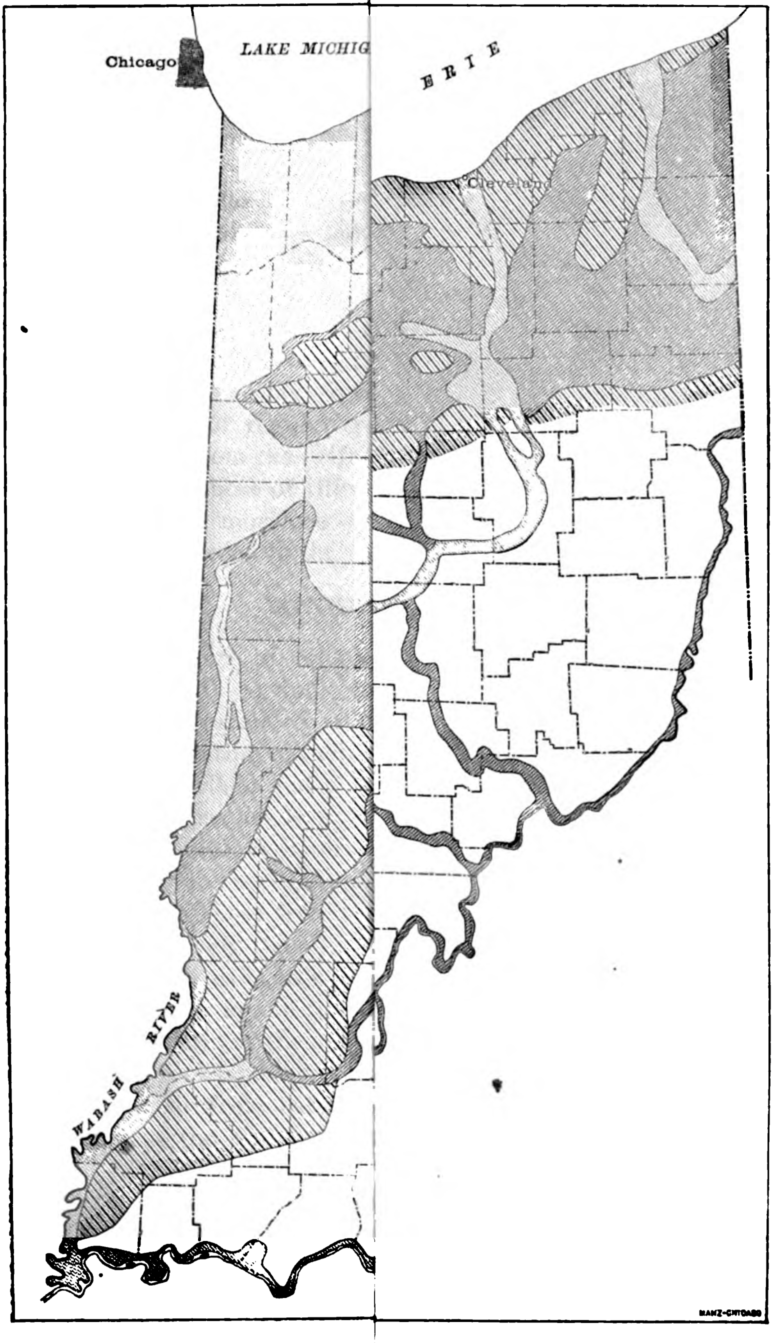
Coal Measures.—The Coal Measures of the southwestern part of Indiana are either unglaciated or covered to only a slight depth with drift, but in western Indiana they are so thickly covered that wells are either obtained in the drift or at the junction of the drift with the rock. Wells which have been sunk into the rock have in some cases struck "copperas water" at moderate depths, and salt water is usually encountered at depths of more than 200 feet. To obtain good water in this region exploration should be made by the drill until fresh water free from sulphates has been reached. Waters with objectionable properties which occur at higher levels can then be cased out, as is impracticable when the wells are dug. In some localities it seems necessary to use rain water collected in cisterns, the sulphates in the waters from the rock being so generally present that good wells are very difficult to obtain.

Tertiary deposits.—The Tertiary deposits are of very limited extent, and the only places in which they appear to be of value as water-bearers are found where the gravels have been redeposited in the Ohio Valley, in which case they sometimes yield springs of considerable strength, some of which are to be found below Rockport.

Drift.—The glacial deposits of Indiana extend to Ohio River, in the southeastern part of the State, but the drift border runs northward from near Jeffersonville to northern Brown County, and thence westward into Monroe County, passing a little north of Bloomington. The course is then southwestward across Greene, Martin, Dubois, Pike, Gibson, and Posey counties to the mouth of the Wabash. From about the latitude of Indianapolis southward the thickness of the drift is very moderate, except along the line of pre-Glacial valleys, but in nearly all parts of the State north of this latitude there is a heavy deposit which in places reaches a thickness of 500 feet, and averages about 200 feet. The average thickness in the entire glaciated portion of the State is estimated to be about 130 feet. There are a few counties in the southeastern part, and small tracts in the southwestern, where the drift is composed very largely of compact clayey material, which is such a poor water-bearer that wells have been sunk into the rock formations. Elsewhere in the State it is the exception to find a well extending to the rock without encountering more or less water-bearing gravel and sand. In the areas of thickest drift the gravel and sand generally greatly preponderate over clayey material. The large amount of gravel and sand in the drift of this State seems due to the fact that there was a crowding or converging of ice lobes which entered the State from the great basins of Lake Michigan, Saginaw Bay, and Lake Erie, which would naturally produce a great amount of glacial drainage.

In the Illinois district, where the single ice lobe from the Lake Michigan basin was free to spread widely, the streams occupied only a small part of the glaciated area, and thus left wide strips in which there was very little movement of waters to carry away the clayey material. In Indiana as well as in Illinois there were oscillations of each of the several ice lobes, which have resulted in alternations of beds of various degrees of coarseness and permeability to water. In the final retreat of the ice an extensive but comparatively thin sheet of sand was deposited over the district between the Kankakee and Tippecanoe rivers in northwestern Indiana, but elsewhere in northern Indiana the surface capping is largely clay. The inferior quality of much of the water in the rock formations of Indiana is more than made good by the great abundance of excellent water in the drift, so that the State is, as a whole, highly favored in its water supply for all domestic uses.

The map of Indiana and Ohio, Pl. XVIII, shows not only the relation of the wells to the drift, but also the parts of the State in which the drift is of exceptional thickness. It should perhaps be stated that in the portion where the drift is but 25 to 75 feet thick wells are commonly obtained without entering the rock, and rock wells are nearly as rare as in the districts where there is more than 100 feet of drift.


Chicago
LAKE MICHIG
ERIE
Cleveland
WABASH RIVER
MANZ-CHICAGO

LOCALITIES FAVORABLE FOR ARTESIAN WELLS IN INDIANA.

There are no extensive areas in this State where artesian wells may be obtained, except perhaps in the northwestern counties where the conditions are similar to those of the neighboring part of Illinois. Elsewhere occasional flows have been obtained in the valleys of the main streams or exceptionally low parts of interfluvial tracts. The deep borings were sunk usually for the purpose of obtaining oil or gas, little attention being given to the head attained by water. The data are therefore insufficient to warrant definite statements concerning the head to be expected at any given place or conclusions concerning the regularity or lack of regularity in the hydrostatic pressure.

Flowing wells from the drift have only been obtained in very small areas, which, like those of Illinois, are situated usually on the iceward side of prominent moraines or in the valleys. Numerous instances will be found recorded in the papers by the author referred to above.

MINERAL WATERS.

Mineral waters are of common occurrence in Indiana, and include the waters of both springs and wells. Mr. W. S. Blatchley has recently made an extended study of such waters and has published a detailed report treating of their character and uses.[a] Over 100 springs or wells are described and a large number of analyses given. Dr. Robert Hessler has made a report on the medicinal properties and uses of Indiana mineral waters.[b]

Springs occur in nearly all parts of the State and in rocks of widely different types. Those from the coal-bearing rocks of the Carboniferous are relatively small, but carry large amounts of mineral matter, especially salt, iron sulphate, iron carbonate, and hydrogen sulphide. The springs in the limestone regions generally carry much lime, but hold little of the substances mentioned as characterizing the Coal Measure rocks. Some of these are of great volume, welling up from fissures, or from between beds, or emerging from caves. In some instances the volume is sufficient to furnish water power for mills.

Up to 1886 few deep wells had been drilled, but since that date more than 14,000 bore holes have been sunk. Some of these flowed, and in many others the water rose nearly to the surface. Large supplies are sometimes obtained. Much of the water is highly mineralized and of medicinal value, and wells have been developed in many instances into important resorts.

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[a] Indiana Dept. Geol. Nat. Resources, Twenty-sixth and Twenty-seventh Ann. Repts., pp. 11-158.

[b] Ibid., pp. 159-224.

The water is to a considerable extent used at the individual wells or springs, but in 1902 shipments from 16 springs amounted to 273,380 gallons, with a value of $236,501. The average price per gallon is the highest in the country.[a] Following is a list of the springs reporting:

Attica Lithia Springs, Attica, Fountain County.
Elliott Springs, Willow Valley, Martin County.
Emerald Spring, Indiana Mineral Springs, Warren County.
French Lick Springs, French Lick, Orange County.
Greenwood Mineral Well, Greenwood, Johnson County.
Kickapoo Magnetic Spring, Kickapoo, Warren County.
King's Mineral Spring, Muddyfork, near Dallas, Clark County.
Laxine Spring, Mount Moriah, Brown County.
Lodi Artesian Well, Silverwood, Fountain County.
Magnetic Mineral Spring, Terre Haute, Vigo County.
Mudlavia, formerly Indiana Mineral Springs, Mudlavia, Warren County.
Mudlavia Artesian Sulphur Spring, Mudlavia, Warren County.
Porter Mineral Springs, near Porter's Depot, Porter County.
Shelbyville Lithia Spring, Shelbyville, Shelby County.
West Baden Springs, West Baden, Orange County.
Winona Lithia Spring, Winona Lake, Kosciusko County.

PRINCIPAL PUBLICATIONS.

Water resources of Indiana and Ohio, by Frank Leverett: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4.

Wells of northern Indiana, by Frank Leverett: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 21, 1899.

Wells of southern Indiana, by Frank Leverett: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 26, 1899.

Description of the Danville quadrangle, by M. R. Campbell and Frank Leverett: Geol. Atlas U. S., folio 67, U. S. Geol. Survey.

Description of the Chicago district, by W. C. Alden: Geol. Atlas U. S., folio 81, U. S. Geol. Survey.

Mineral waters of Indiana, by W. S. Blatchley: Indiana Geol. Survey, vol. 26, pp. 11-158.

The medicinal properties of Indiana mineral waters, by Robert Hessler: Indiana Geol. Surv., vol. 26, pp. 159-226.

Description of the Ditney quadrangle, by M. L. Fuller and G. H. Ashley: Geol. Atlas U. S., folio 84, U. S. Geol. Survey.

Description of the Patoka quadrangle, by M. L. Fuller and F. G. Clapp: Geol. Atlas U. S., folio 105, U. S. Geol. Survey.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

OHIO.

By FRANK LEVERETT.

INTRODUCTORY STATEMENT.

A somewhat detailed discussion of drainage systems, mineral springs, and water supply for cities and villages will be found in a paper by the author which appears in the Eighteenth Annual Report of the United States Geological Survey.[a] The drainage features, both present and pre-Glacial, and the glacial formations in their relation to water supplies are treated at some length by the author in Monograph XLI of this survey. The rock waters and flowing wells of Ohio are discussed by Edward Orton in a paper in the Nineteenth Annual Report of the United States Geological Survey. The paper covers the subject of the relative value of the several geologic formations as water-bearers. In Ohio the State board of health is required by law to approve all public water supplies when introduced, and their reports may be consulted for analyses made in accordance with this law. A report published in 1898 contains an exceptionally full discussion of water supplies, and includes the paper by Orton, referred to above.

GEOLOGIC COLUMN.

[Modified from paper of Edward Orton in Nineteenth Annual Report of the U. S. Geological Survey.]

Formation.	Thickness.
	Feet.
Recent deposits, alluvium, peat, marl, etc.	5–50
Wisconsin drift sheet (Pleistocene)	0–300
The loess or white clay (Pleistocene)	3–15
Illinoian drift sheet (Pleistocene)	10–250
Upper Barren Coal Measures (Carboniferous)	500±
Upper Productive Coal Measures (Carboniferous)	200±
Lower Barren Coal Measures (Carboniferous)	500±
Lower Productive Coal Measures (Carboniferous)	250±
Conglomerate Coal Measures (Carboniferous)	250±

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[a] Water resources of Indiana and Ohio, Eighteenth Ann. Rept., pt. 4, pp. 425–559.

Formation.	Thickness.
	Feet.
Logan group (Eocarboniferous)	0-300
Cuyahoga shale (Eocarboniferous)	150-450
Berea shale and grit (Carboniferous)	25-150
Bedford shale and sandstone (Carboniferous)	50-150
Ohio shale, etc. (Devonian)	250-2,500+
Corniferous limestone (Devonian)	25-100
Onondaga limestone (Silurian)	20-600
Niagara group, limestone and shale (Silurian)	150-350
Clinton limestone (Silurian)	20-150
Medina shale (Silurian)	25-150
Hudson River group, shales and limestones (Ordovician)	300-800
Utica shale (Ordovician)	0-300
Trenton group (Ordovician)	300-600

CHARACTERISTICS OF WATERS OF DIFFERENT DEPTHS.

The following general principles have been stated by Orton in the report above mentioned:

1. The subterranean waters from a comparatively shallow depth carry, as a rule, dissolved carbonates. Lime and magnesia are the leading bases, but potassium and sodium also occur in small quantities. Iron is unfailingly present, and often in notable quantity. These wells are common sources of potable supply.

2. Water from a greater depth holds dissolved chlorides as well. Chloride of sodium is by far the most common, but chlorides of magnesium and calcium are also often added. The presence of chlorides is seldom shown in water at less than 100 feet in depth, and where found they are confined to a few formations of the Ohio column. It is very rare that the drill descends to 300 feet without encountering saline water or water too highly mineralized with other elements to be acceptable for the highest uses. Aside from that of a few wells in glacial drift no water of the State is known that comes from a depth greater than 500 feet and still remains free enough from mineral solutions to warrant its use as potable.

3. Sulphates are generally found in the deeper waters, but are also found in the shallower waters. The most common compound is calcium sulphate; but sodium sulphate is not infrequent.

4. Sulphides also, particularly sulphureted hydrogen, though often rising to the surface in so-called sulphur springs, are especially characteristic of waters found in limestones, and nearly all of the water of the great Ohio shale system is characterized in this way. Sulphides pass into sulphates very promptly and by reactions easily understood.

RELATIVE VALUE OF DIFFERENT ROCK FORMATIONS AS WATER-BEARERS.

Of the large number of formations present in Ohio, as indicated in the section above, Orton considers only the following to be important water-bearers: Trenton limestone, Clinton limestone, Niagara limestone, Onondaga limestone, Corniferous limestone, Logan sandstone, Berea grit, Carboniferous conglomerates, and certain sandstone beds of the Coal Measures.

Trenton limestone.—The waters of the Trenton limestone are all highly mineralized and have a strong, bitter, or saline taste; they are also charged heavily with sulphureted hydrogen.

Clinton limestone.—The Clinton limestone affords a large number of springs along its outcrop in Preble, Montgomery, Warren, Greene, and Clinton counties. This limestone when under a deep cover of later formations carries water too highly mineralized for a potable supply. It is therefore utililized for domestic purposes only along the line of outcrop.

Niagara limestone.—The Niagara limestone contributes its most important supplies of water where it immediately underlies the glacial drift in a few counties in the western part and a narrow strip leading from there southward to Ohio River in Adams County. Orton refers to the effect of atmospheric agencies in enlarging the joints of the limestone and establishing underground reservoirs and channels for waters which sink into this formation from the overlying drift deposits.

Onondaga limestone.—The Onondaga limestone is considered by far the most important source of underground water. The great area of its outcrop in the west-central and northern portions of the State, as well as the thickness of the formation and its soluble character, furnish the basis for this estimate. A considerable number of cities and villages depend upon this limestone for water supply.

Corniferous limestone.—The Corniferous limestone is considered of small importance as a source of water because of its comparatively small area of outcrop. Several flowing wells in the city of Columbus have, however, been obtained from it, and there are numerous springs issuing from it along the Scioto Valley.

Logan sandstone.—The Logan sandstone is a water-bearing stratum wherever found at the surface. It outcrops prominently in Richland, Ashland, and Wayne counties. Artesian wells have been obtained from it at several points in Wayne County, and the water supply of Orrville is from this source.

Berea grit.—The Berea grit is also a good water bearer along the line of its outcrop and often affords supplies when covered by the Cuyahoga shale to moderate depths. Such is the case at the village of New London.

Coal Measures.—The Conglomerate Coal Measures contain a white and pebbly sand of great purity—the Sharon conglomerate—which in its outcrop in northeastern Ohio affords excellent wells. The city of Massillon now derives its supply from this source. Cuyahoga Falls also stands on this conglomerate and the wells of the village are largely obtained in it.

The water supply of the Coal Measures proper is rather inferior. Excellent water can be secured almost everywhere, but it is considered doubtful if the supply will be adequate for the growing towns that are located within the boundaries of this formation. It is probable that the streams of the region will need to be drawn upon for public water supply.

Drift.—The glacial deposits furnish by far the largest amount of potable water to be obtained within the State. These deposits cover nearly three-fourths of the State, the southeastern portion only being unglaciated. The valley gravels have been carried down the main valleys of the driftless portion of the State and hold much of the water of the valley drainage at convenient depth for wells; the quality of water is generally excellent. The Illinoian drift sheet extends beyond the Wisconsin only in a few counties in the central and southwestern parts of the State. This drift sheet is composed largely of clayey material except along the line of pre-Glacial valleys, where there is found to be a large filling of sand or coarser water-bearing material. Within the limits of the Wisconsin drift the moraines are usually composed in large part of gravelly or sandy material, but in some cases wells have to be sunk to considerable depth to strike strong water veins. On the plains between the moraines beds of sand and gravel are usually found sandwiched between beds of clay or till at convenient depth. Throughout the greater part of the drift-covered portion of the State good wells are obtained at depths of 50 feet or less, and there are only a few localities in which it is necessary to sink to depths of 100 feet or more. There are, however, localities in which strong supplies are obtained at moderate depth, and yet borings have been sunk 100 feet in order to obtain flowing wells.

Much of the surface portion of the drift is a clayey material which protects wells obtained in underlying deposits from surface contamination. Even the areas covered by great glacial lakes in the northwest part of the State have usually a clayey soil, the principal exception being a belt of sand north of Maumee River in Fulton and Lucas counties. The relation of wells to drift formations may be seen by reference to the map, Pl. XVIII.

LOCALITIES FAVORABLE FOR ARTESIAN WELLS.

Artesian wells from rock formations are comparatively rare, although the water is usually under considerable hydrostatic pressure. Orton calls attention to strong flowing wells near Orrville obtained from the Logan conglomerate or sandstone and to flows at Massillon from the Sharon conglomerate and to a few others at points scattered over the State. There appears to be no extensive areas of artesian water open to development in the State from any of the rock formations. The glacial deposits are a much more productive field for exploration.

Flowing wells have been obtained without entering the rock in a belt on the inner slope of the great morainic system that runs from southeastern Michigan across northwestern Ohio into Indiana. Hundreds of wells have already been obtained in Williams, Defiance, and Fulton counties. The wells range from shallow fountains, differing but little from boiling springs, in which pipes are driven only 10 to 20 feet into the ground up to borings nearly 200 feet in depth. In much of that region the thickness of the drift is 150 to 200 feet or more. Flowing wells are also found along the line of deep pre-Glacial channels in Allen, Auglaize, and Mercer counties at depths ranging from 100 feet or less up to 350 feet, and wells have in some cases been continued to depths of more than 400 feet without striking the rock. Records of many of these wells are presented in the report by Orton, mentioned above. There are many other places in Ohio where flowing wells are found in small areas of a square mile or less to which attention has been directed by the author in Monograph XLI. These wells are usually on the iceward slope of moraines, and the region of intake is probably restricted largely to the moraine adjacent to them. They are of various depths, from 20 feet or less up to 100 feet or more. Probably further exploration with deep borings would enlarge such flowing well areas or increase the number of areas in which flows are obtained, for in a great many districts the occurrence of abundant water at moderate depths has freed the residents from the necessity of drilling deeply to test the chances for artesian waters.

MINERAL SPRINGS.

Both the drift and the rocks of Ohio yield a considerable number of springs. The springs of the drift vary with the nature of the local materials, but are generally hard and may carry much iron. The rock waters of the Coal Measures are frequently salt or chalybeate, while those of the limestones are generally hard. Many of the springs have been developed as resorts, while others place their water on the market for medicinal or other purposes. Twenty such springs reported sales in 1902, the amount of which aggregated 1,948,840 gallons, with a value of $172,746.[a] The springs reporting are as follows:

Alba Spring, Rockfort, Cuyahoga County.
Arcadian Springs, Mineral Springs, Adams County.
Buckeye Lithia Spring, near Martins Ferry, Belmont County.
Concord Crystal Spring, Concord, Lake County.
Crum Mineral Spring, Austintown, Mahoning County
Crystal Rock Spring, near Sandusky, Erie County.
Deerfield Mineral Springs, Deerfield, Portage County.
Fargo Mineral Springs, Ashtabula, Ashtabula County.
Green Spring Artesian Mineral Well, Green Springs, Sandusky County.
Knisely Mineral Springs, Bucyrus, Crawford County.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 996.

La Fountaine Springs, Fountain Park, Champaign County.
Magnetic Magnesia Well, Canton, Stark County.
Oakridge Spring, Greensprings, Sandusky County.
Painesville Mineral Spring, Painesville, Lake County.
Puritas Spring, Rockport, Cuyahoga County.
Purtlebaugh Mineral Spring, Urbana, Champaign County.
Rex Ferro-Lithia Springs, New Richmond, Clermont County.
Ripley Brom-Lithia Springs, Ripley, Brown County.
Talewanda Mineral Springs, near College Corner, Preble County.
Wheeler Mineral Springs, Youngstown, Mahoning County.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 130–134.
Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, pp. 21–28.
Water resources of Indiana and Ohio, by Frank Leverett: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4.
Rock waters of Ohio, by Edward Orton: Nineteenth Ann. Rept. U. S. Geol. Survey, pt 4.

WEST VIRGINIA.

By M. L. Fuller.

West Virginia has through a large portion of its area a rugged topography. It is mountainous only in the eastern part, where it borders the Appalachian ridges, but even in the western portion it is so cut by streams with intervening narrow ridges that there is little even moderately level land, except the narrow strips along some of the streams. The conditions are therefore very favorable for springs, which, with spring-fed streams, constitute the main source of water supply over a large part of the State.

Topographically and geologically it may be divided into two distinct belts: (1) The Appalachian Mountain belt, including the Shenandoah Valley, and (2) the Cumberland Plateau.

APPALACHIAN MOUNTAIN BELT.

This term is here used, as elsewhere in the report, in its broad sense, and includes the area of folded rocks lying between the crystalline rocks of the Piedmont Plateau of Virginia on the east, and the area of gently folded to nearly flat rocks of the Allegheny Plateau on the west. The belt is crossed by the "handle" of West Virginia, and a narrow strip along its whole eastern boundary is included. The rocks are mainly Cambrian, Silurian, and Devonian in age, although a few small areas of Carboniferous rocks are included, especially near the western borders of the belt. The rocks include quartzites, sandstones, shales, and limestones, the latter occurring principally in the Shenandoah Valley at the extreme eastern extension of the panhandle, and as a strip along the western base of the mountain belt. The former belongs to the Cambro-Silurian rocks, and the latter to the Carboniferous.

Except in the Shenandoah and other smaller valleys, this area is thinly inhabited, and small springs constitute the main source of water supply. In the limestone valleys wells are sometimes resorted to, but reliance in the main is placed on cisterns, because of the uncertainty of the occurrence of water in the limestone. A few large springs issue from the limestones, from the more porous sandstones, and more rarely from the shales. The waters are often mineralized and of medicinal value, and a considerable number of springs have been developed as resorts. Some of the waters are thermal.

CUMBERLAND PLATEAU.

The greater portion of the area of the State falls within what may be termed the Cumberland Plateau, which may be considered as entering the State from Kentucky on the south. The plateau does not present an even surface, but has been cut by streams until only narrow-crested ridges remain to represent the original level. In a broad way the slope is to the northwest, away from the mountains, the altitude varying from 3,500 feet at the western base of the mountains to less than 1,000 feet near the Ohio River. The river bottoms are sunk several hundred feet below the upland level. At the northern boundary of the State the Cumberland Plateau merges with the Allegheny Plateau of Pennsylvania.

The rocks belong mainly to the coal-bearing division of the Carboniferous, and are either inclined at a low angle or gently folded. Because of the numerous springs few attempts have been made to obtain water by deep borings, but the wells drilled for oil and gas frequently obtain abundant water, some of which flows in the synclines or under other favorable conditions.

The stratified deposits along Ohio River and some of the other large streams yield good water to shallow wells, but their area is limited.

MINERAL SPRINGS.

In 1902 nine springs reported sales of mineral water. The total output is stated to be 92,310 gallons and to have a value of $25,343.[a] Several of the springs are also developed as resorts.

Capon Springs, Capon Springs, Hampshire County.
Greenbrier Alum Spring, near Lewisburg, Greenbrier County.
Greenbrier White Sulphur Springs, White Sulphur Station, Greenbrier County.
Magnesia Spring, No. 2, near Wheeling, Ohio County.
Manacea Irondale Spring, near Independence, Preston County.
Pence Spring, Pence Springs, Summers County.
Red Sulphur Springs, Red Sulphur Springs, Monroe County.
Triplet Well, Calf Creek, Grant District, Pleasants County.
Webster Springs, Webster Springs, Webster County.

PRINCIPAL PUBLICATIONS.

Mineral springs of the United States, by A. C. Peale: Bull. U. S. Geol. Survey No. 32, pp. 69–73.

Preliminary list of deep borings in the United States, pt. 2, by N. H. Darton: Water-Supply and Irrig. Paper U. S. Geol. Survey No. 61, pp. 61–64.

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[a] Peale, A. C., Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904 p. 996.

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CHARLES D. WALCOTT, Director

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Page 11. Fig. 1 should have had the title "Profile of Catawba River from Marion to Connelly Springs, N. C.," and been placed at page 13.

Page 14. Pl. II should have had the title "Profile of Tallulah River below Blalock, Ga.," and been placed at page 18.

Page 19. Fig. 2 should have had the title "Profile of Tugaloo River below Tallulah Falls, Ga.," and been placed at page 23.

Page 24. Fig. 3 should have had the title "Profile of Savannah River from Andersonville, S. C., to Lisbon, Ga.," and been placed at 29.

Page 30. Pl. III should have had the title "Profile of South and Ocmulgee rivers from Constitution to Macon, Ga.," and been placed at page 46.

Page 47. Fig. 6 should have had the title "Profile of Alcovy River below Dabney's bridge, Georgia," and been placed at page 56.

Page 56. Fig. 8 should have had the title "Profile of upper Chattahoochee River from Nacoochee, Ga., to junction with Chestatee River," and been placed at page 61.

Page 62. Fig. 10 should have had the title "Profile of lower Chattahoochee River from West Point to Columbus, Ga.," and been placed at page 71.

Page 73. Fig. 12 should have had the title "Profile of Chestatee River below Willow, Ga.," and been placed at page 77.

Page 76. Pl. IV should have had the title "Profile of Chippewa River from Reeds Landing, Minnesota, to Flambeau, Wis.," and been placed at page 98.

Page 103. Fig. 18 should have had the title "Profile of Buffalo River from Flatwoods to Lobelville, Tenn.," and been placed at page 11.

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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Hydrographic Branch,
Washington, D. C., July 23, 1904.

Sir: I have the honor to transmit herewith a paper entitled "River Surveys and Profiles Made in 1903," which has been arranged by W. Carvel Hall and John C. Hoyt.

This paper contains the results of the cooperative river surveys carried on during 1903 between the topographic and hydrographic branches.

There is a large demand for the data herein presented by engineers and others interested in power development. I therefore recommend that this manuscript be published as a Water-Supply and Irrigation Paper.

Very respectfully,
F. H. Newell,
Chief Engineer.

Hon. Charles D. Walcott,
Director United States Geological Survey.

RIVER SURVEYS AND PROFILES OF 1903.

Arranged by W. C. HALL and J. C. HOYT.

INTRODUCTION.

In order to determine the location of the undeveloped water powers on the various rivers in the United States the United States Geological Survey has from time to time made surveys and profiles of the more important of the rivers on which possible power sites were known to be located. The object of these surveys is to point out localities where power may be developed.

In the determination of the river profiles the general plan of survey adopted was as follows:

The elevations were based upon reliable heights derived from primary or precise levels of the United States Geological Survey. On this datum, with few exceptions, lines of flying levels were carried up the bank of each stream and bench marks were established at intervals of about 1 mile, usually on nails on tree roots. The elevations of the surface of the water at the head and foot of each shoal, rapid, or fall were noted. These levels, with few exceptions, have been tied at both ends. In the case of Broad River primary levels were used instead of flying levels, and regulation bronze tablets left at intervals of 6 miles.

The horizontal control of the survey was by plane table oriented by compass, while the distance was always obtained by means of stadia measurements. To further insure the accuracy of the work, the stadia rod was so divided that one division on it equaled one division of the scale used in plotting.

The field sheets were plotted on the scale of 1 : 22,500, with the exception of the surveys of the Tallulah and Tugaloo rivers, which were on the scale of 1 : 45,000. Several different runs of river were plotted on the same plane-table sheet, the ends of the different sections being so marked that there would be no difficulty in joining them and making one continuous map.

On these sheets were shown the outlines of the river banks, the islands, the positions of rapids, shoals, falls, and existing dams, the crossings of all ferries and roads, and as much of the culture of the river bottom as could be obtained without leaving the immediate neighborhood of the river. The river banks were contoured carefully and the adjacent river bottoms sketched, all with an interval of 10 feet. On these field sheets are marked in their proper positions the elevations of the various bench marks left, as are also the elevations of the water surfaces wherever obtained.

For each river surveyed, first are given a brief description, a list of the elevations, and a condensed profile of the portion of the river surveyed.

The elevations as given in the original notebooks have been adjusted in accordance with the various primary heights tied to, and the figures herein given are the ones obtained from this adjustment.

On file in the Washington office are the original topographic sheets and profiles on the scale of 1 inch to a mile horizontal and 1 inch to 100 feet vertical.

ACKNOWLEDGMENTS.

In the collection of these data and their preparation for publication special acknowledgment is due to the levelmen and others who carried on the surveys. Acknowledgment is due, also, to Messrs. B. M. Hall and M. R. Hall for suggestions, and to Messrs. C. B. Kendall and D. H. Baldwin, who adjusted the various lines of levels, under the supervision of Mr. S. S. Gannett, geographer.

BUFFALO RIVER FROM FLATWOODS TO LOBELVILLE, TENN.

A line of flying levels was run on Buffalo River, Tennessee, from the mouth of Little Opossum Creek, near Flatwoods, to Standing Rock Ford, about 3 miles north of Lobelville—a distance of 47 miles. The plane-table survey was on the scale of 1: 22,500. During the course of the work 28 bench marks on tree roots were marked and 39 water-surface elevations were recorded.

The total fall of that stretch of the river is 109 feet, and is so evenly distributed that there seems to be no power site of any value. There are now two crude dams, one near Linden and the other near Lobelville, supplying power for small gristmills, but at neither place do the conditions warrant the construction of more substantial dams.

The soil near the river is fertile and well adapted to the cultivation of corn, hay, and peanuts.

The elevations in the following list are based upon an assumed elevation of 537.25 feet for the water surface at the mouth of Little Opossum Creek as interpolated from contours sketched on the Mannie sheet. The assumed elevation is probably within 20 feet of correct datum.

The leveling was done October 4 to 31, 1903, under the direction of Oscar Jones, topographer, by Ralph Hutchins, levelman.

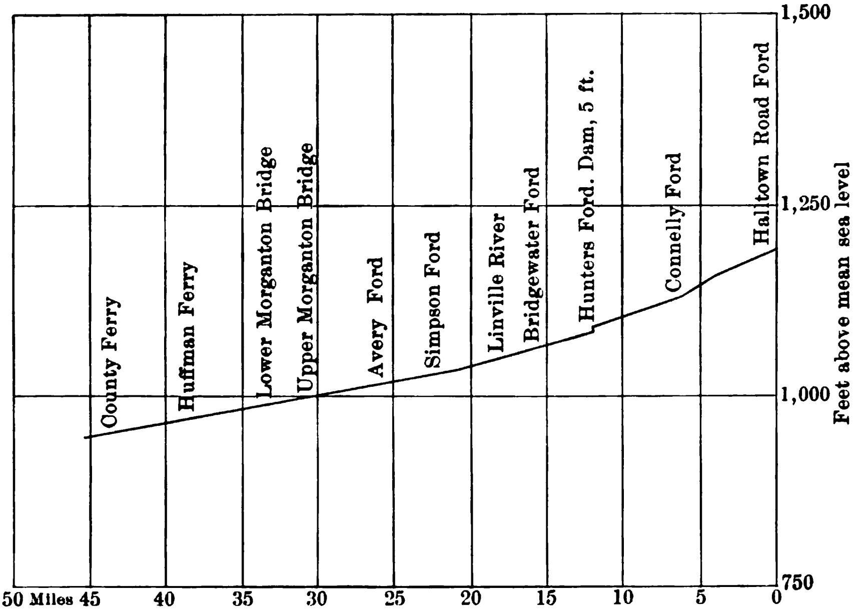


FIG. 1.—Profile of Buffalo River from Flatwoods to Lobelville, Tenn.

Elevations on Buffalo River, Tennessee, from Little Opossum Creek to Standing Rock Ford.

Distance in miles.		Elevation in feet.
0.0	Little Opossum Creek, mouth of; east side of river at ford, hackberry tree, nail in root of	537.25
.0	Surface of water	533
.3	East side of river at ford, nail in root of elm tree	532.26
.6	Ford, east side of, dead sycamore tree, nail in root of	531.59
1.0	Ford, 125 feet north of; east side of river, nail in root of sycamore tree.	532.32
1.2	Surface of water	528
2.1	Ford, south side of river, nail in root of sycamore tree	529.06
2.2	600 feet north of ford, surface of water	525
4.1	Sinking Creek, east side of river, maple tree, nail in root of	524.90
4.1	Sinking Creek, mouth of, surface of water	520
6.3	Ford, 275 feet north of, north bank of river, east side of highway, at angle, nail in root of sycamore tree	521.16
6.2	Ford, 650 feet west of; surface of water	512
8.9	50 feet from river, south side of; sycamore tree, nail in root of	510.01
8.9	Surface of water	503
10.6	Ford, east bank of river, sycamore tree, nail in root of	500.70
10.8	Hurricane Creek, mouth of; surface of water	498
11.9	Hurricane Creek, 1.1 miles from; 50 feet east of ford, nail in root of beech tree	504.17

Elevations on Buffalo River, Tennessee, from Little Opossum Creek to Standing Rock Ford—Continued.

Distance in miles.		Elevation in feet.
11.9	Surface of water	494
13.2	At ford, east bank of river, nail in root of willow tree	489.53
13.2	Surface of water	487
15.2	At ford, south bank of river, nail in root of maple tree	484.23
15.2	Ford, 800 feet west of; surface of water	482
15.5	Ford, south bank of river, nail in root of sycamore tree	485.15
16.6	Ford, east bank of river, nail in root of sycamore tree	482.29
16.8	County bridge, west abutment, bolt in base of girder	499.45
17.3	Ford, east bank of, nail in root of sycamore tree	483.03
17.3	Surface of water	477
19.9	Coon Creek Ford, east bank of river, nail in base of willow tree	476.42
19.9	Ford, 350 feet north of, surface of water	471
21.3	Ford, 106 feet west of; west bank of river, nail in base of willow tree	470.04
21.3	Ford, surface of water	467
22.3	Ford, east bank of river, screw in base of sycamore tree	469.70
22.3	Ford, surface of water	465
22.6	Brush creek, east bank of river, nail in root of sycamore tree	467.29
22.6	Surface of water	465
23.7	Above dam, surface of water	464
23.7	Below dam, surface of water	459
24.2	Ford, west bank of river, top of large rock	459.32
24.2	Ford, 600 feet below, surface of water	457
26.1	Ford, west bank of river, top of large rock	454.16
26.1	Surface of water	452
26.6	Beardstown, east bank of river, at ford, nail in root of sycamore tree	454.24
26.6	650 feet below ford, surface of water	451
28.1	Ford, west bank of river, nail in root of sycamore tree	452.90
29.7	Ford, east bank of river, nail in root of hackberry tree	449.51
30.3	Ford, south bank of river, road, south side, nail in root of sycamore tree	445.47
30.3	Ford, 650 feet below, surface of water	441
31.9	Above dam, surface of water	441
31.9	Below dam, surface of water	435
31.9	Ford, south bank of river, road, west side, nail in root of sycamore tree	438.32
34.3	Ford, east bank of river, nail in base of sycamore sapling	434.02
34.3	Surface of water	431
35.4	Dodson Ford, east bank, top of rock	430.51
36.4	Hester Ford, surface of water	426.59
40.9	Logan Ford, south bank, west side of road, nail in base of willow tree	419.08
41.2	Standing Rock Ford, south bank, nail in root of maple tree	420.61

CATAWBA RIVER FROM MARION, N. C., TO CONNELLY SPRINGS, N. C.

Catawba River was surveyed from the Halltown road crossing, near Marion, N. C., down the river to the mouth of Johnsons Mill Creek, near Connelly Springs, N. C.—a distance of 45 miles. A line of flying levels was run in connection with the plane-table stadia traverse, which was on the scale of 1:22,500, based on a permanent bench mark of the United States Geological Survey at Marion, N. C. This flying line is connected with a precise line along the Southern Railway, run by the Geological Survey in 1896, at Bridgewater, Glen Alpine, Morganton, and Connelly Springs, at each of which points there is a permanent bench mark. There were only three temporary bench marks set along the river, but there were 160 water-surface elevations recorded, all of which were adjusted to the mean reading on the gage established at the upper bridge near Morganton. The work was done in July, August, and September, 1903, by R. C. Howard and S. A. Obenshain, under the direction of W. C. Hall, topographer.

In the stretch of river surveyed there is a total fall of 243 feet. At present there is only one crude dam—at John River Road Ford, where there is a fall of 4 feet, supplying power to operate Hunter's gristmill. There is a dam site near Connelly Ford. The combined fall of two shoals about half a mile apart is 12.3 feet and a long, rocky island in the lower part of the shoal would somewhat facilitate the construction of a dam. At this point the river is about 200 feet wide, with rocky cliffs on both banks. The river bottom is very fertile, the principal crops being corn and hay.

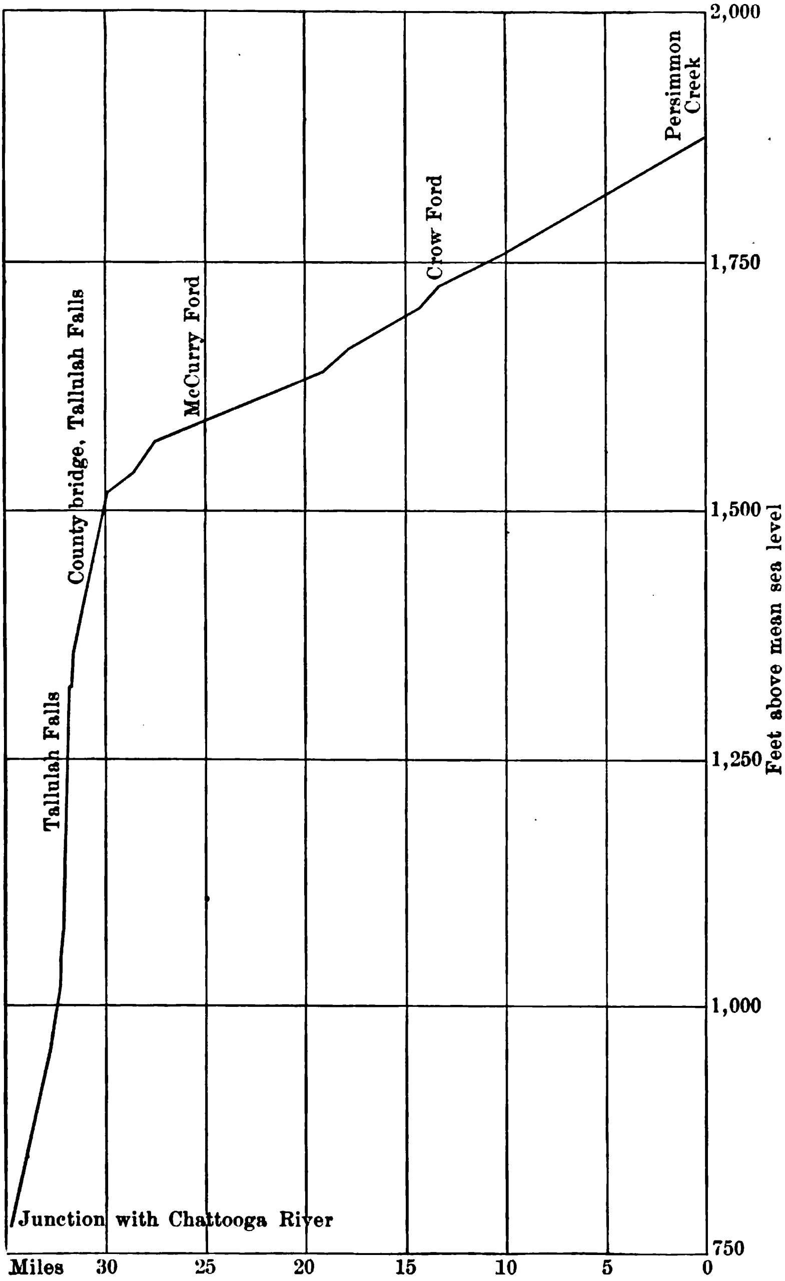
Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.

Distance in miles.		Elevation in feet.
0.0	Halltown Road Ford, head of island, head of shoals, surface of water.	[a]1,189
.1	Foot of shoals, surface of water	1,187
.2	Head of shoals, surface of water	1,187
.2	Foot of shoals, surface of water	1,184
.5	Head of shoals, surface of water	1,184
.7	Foot of shoals, surface of water	1,179
1.1	Mouth of North Fork, 0.5 mile above, head of shoals, surface of water	1,179
1.1	Foot of shoals, surface of water	1,177
1.3	Head of shoals, surface of water	1,177
1.3	Foot of shoals, surface of water	1,175
1.7	Head of shoals, surface of water	1,174
1.8	Foot of shoals, surface of water	1,172
2.1	Head of shoals, surface of water	1,170
2.3	Foot of shoals, surface of water	1,167

[a] Adjusted to bench mark at Marion; McDowell County court-house; west face, at south end of portico, bronze tablet marked "1438"; elevation, 1,436.857 feet.

Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.—Cont'd.

Distance in miles.		Elevation in feet.
2.4	Head of shoals, surface of water	1,166
3.2	Foot of shoals, surface of water	1,157
3.4	Head of shoals, surface of water	1,156
3.4	Foot of shoals, surface of water	1,154
4	Head of shoals, surface of water	1,153
4.2	North bank of island, foot of shoals, surface of water	1,146
4.4	Head of island, head of shoals, surface of water	1,146
4.4	Foot of island, foot of shoals, surface of water	1,141
4.7	Head of shoals, surface of water	1,140
4.7	Foot of shoals, surface of water	1,137
4.8	Head of shoals, surface of water	1,137
4.8	Foot of shoals, surface of water	1,134
5.1	Head of shoals, surface of water	1,134
5.1	Foot of shoals, surface of water	1,133
5.3	Head of shoals, surface of water	1,133
5.3	Foot of shoals, surface of water	1,131
5.4	Head of shoals, surface of water	1,131
5.4	Foot of shoals, surface of water	1,130
5.7	Connelly Ford, head of shoals, surface of water	1,130
5.8	Foot of shoals, surface of water	1,127
6	Head of shoals, surface of water	1,126
6	Foot of shoals, surface of water	1,126
6.1	Head of shoals, surface of water	1,125
6.1	Small island in shoals, foot of shoals, surface of water	1,124
6.6	Between large islands, head of shoals, surface of water	1,124
6.7	Foot of islands, foot of shoals, surface of water	1,122
6.9	At head of broad flood channel, head of shoals, surface of water	1,122
7	Foot of shoals, surface of water	1,119
7.3	At foot of broad channel, head of shoals, surface of water	1,119
7.3	Foot of shoals, surface of water	1,116
7.5	Head of shoals, surface of water	1,116
7.5	Foot of shoals, surface of water	1,115
7.8	Head of shoals, surface of water	1,115
7.8	Foot of shoals, surface of water	1,114
8.2	Head of shoals, surface of water	1,113
8.5	Foot of shoals, surface of water	1,108
8.5	Head of shoals, surface of water	1,108
8.7	Foot of shoals, surface of water	1,105
9.2	John River Road, head of shoals, surface of water	1,103
9.2	Foot of shoals, surface of water	1,102
9.8	Just below ford, head of shoals, surface of water	1,101
9.8	Foot of shoals, surface of water	1,099



PROFILE OF CATAWBA RIVER FROM MARION TO CONNELLY SPRINGS, N. C.

Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.—Cont'd.

Distance in miles.		Elevation in feet.
10	Head of island, head of shoals, surface of water	1,099
10.2	Foot of shoals, surface of water	1,094
10.8	Head of shoals at head of island, surface of water	1,094
10.9	Foot of island, foot of shoals, surface of water	1,092
11.1	Head of shoals, surface of water	1,092
11.1	Foot of shoals, surface of water	1,089
11.6	Just above dam, surface of water	1,089
11.6	Below ford, foot of shoals, surface of water	1,084
12	Head of shoals, surface of water	1,083
12	Foot of shoals, surface of water	1,079
12.4	Head of shoals, surface of water	1,079
12.4	Foot of shoals, surface of water	1,079
13	Head of shoals, surface of water	1,078
13.1	Foot of shoals, surface of water	1,075
13.3	Head of shoals, surface of water	1,075
13.3	Foot of shoals, surface of water	1,074
13.5	Below head of island, head of shoals, surface of water	1,074
13.7	Foot of two islands, foot of shoals, surface of water	1,070
13.9	Head of shoals, surface of water	1,070
13.9	Foot of shoals, surface of water	1,070
14.4	Head of shoals, surface of water	1,069
14.4	Foot of shoals, surface of water	1,069
14.5	Bridgewater, in front of station, top of north rail	[a]1,095.7
14.5	Head of shoals, surface of water	1,068
14.6	Foot of shoals, surface of water	1,068
15	Head of shoals, surface of water	1,067
15	Foot of shoals, surface of water	1,066
15.1	Just above head of shoals, surface of water	1,066
15.2	Head of shoals, surface of water	1,065
15.2	Foot of shoals, surface of water	1,062
15.4	Head of shoals, surface of water	1,062
15.5	Foot of shoals, surface of water	1,062
15.8	Head of shoals, surface of water	1,061
15.9	Foot of shoals, surface of water	1,061
16.4	Head of shoals, surface of water	1,058
16.8	Foot of shoals, surface of water	1,056
17	Head of shoals, surface of water	1,054
17.2	Foot of shoals, surface of water	1,054
18	Just above head of upper island, head of shoals, surface of water	1,051
18.1	Between island and south bank of river, foot of shoals, surface of water	1,049

[a] Bridgewater, 0.4 mile east of; bridge seat at west end of Muddy Creek Bridge, 2.75 feet south of south rail, copper bolt marked "U. S. G. S., 1091;" elevation, 1,089.549 feet.

Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.—Cont'd.

Distance in miles.		Elevation in feet.
18.2	Mouth of Linville River, below ford, at head of island and south bank, head of shoals, surface of water	1,048
18.4	Between island and south bank, foot of shoals, surface of water	1,046
18.7	Head of small island, head of shoals, surface of water	1,045
18.7	Center of island, foot of shoals, surface of water	1,045
18.9	Head of two small islands, head of shoals, surface of water	1,045
19.1	Foot of shoals, surface of water	1,040
19.6	Long narrow island along north bank, head of short shoal, surface of water	1,039
19.8	Head of shoals, surface of water	1,038
19.8	Foot of shoals, surface of water	1,037
20.1	Above ford, head of shoals, surface of water	1,036
20.3	Head of shoals, surface of water	1,035
20.4	Foot of shoals, surface of water	1,033
20.9	Head of shoals, surface of water	1,032
20.9	Foot of shoals, surface of water	1,031
21.3	Head of shoals, surface of water	1,031
21.3	Foot of shoals, surface of water	1,030
21.5	Head of shoals, surface of water	1,030
21.7	Head of large island, head of shoals, surface of water	1,030
22	250 feet below foot of large island, foot of shoals, surface of water	1,026
22.4	Ford, head of shoals, surface of water	1,026
22.5	Foot of shoals, surface of water	1,025
23.4	Head of shoals, surface of water	1,024
23.7	Head of shoals, surface of water	1,023
23.7	Foot of shoals, surface of water	1,022
24	Head of shoals, surface of water	1,022
24.3	Foot of shoals, surface of water	1,016
25	Avery Ford, 50 feet above, head of shoals, surface of water	[a] 1,015
25	Foot of shoals, surface of water	1,013
25.4	Head of shoals, surface of water	1,013
25.4	Foot of shoals, surface of water	1,012
26.6	Between long island and north bank of river, head of shoals, surface of water	1,009
26.6	Foot of shoals, surface of water	1,007
27.2	Surface of water	1,006
28.1	Head of shoals, surface of water	1,004
28.2	Head of long narrow island, foot of shoals, surface of water	1,003
29	Greenlea Ford, head of shoals, surface of water	1,001
29.1	Foot of shoals, surface of water	1,001

[a] Circuit from White Ford to Avery Ford is adjusted to Glen Alpine, 73.2 feet north of north rail of main track, southeast corner of brick basement of Hennessee & Co.'s store, bronze tablet marked '1215;" elevation, 1,213.944 feet.

Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.—Cont'd.

Distance in miles.		Elevation in feet.
29.4	Between island and mouth, head of shoals, surface of water	1,000
29.6	Foot of island, foot of shoals	998
29.9	Head of shoals, surface of water	998
29.9	Foot of shoals, surface of water	997
30.2	Upper Morganton Bridge, head of shoals under, surface of water	[a] 996
31.7	Fleming Ford, head of islands at, head of shoals, surface of water	992
32	Foot of shoals, surface of water	988
33	Lower Morganton Bridge, under, surface of water	986
33.5	Head of shoals, surface of water	986
34.2	Foot of shoals, surface of water	977
34.4	Head of shoals, surface of water	976
34.8	Below island at mouth of creek on south bank, foot of shoals, surface of water	974
35.5	Mouth of John River, surface of water	972
37.1	Head of shoals, surface of water	969
37.9	Foot of shoals, surface of water	963
38.5	Huffman Ferry, north bank, west side of road, nail in post	974.2
	Huffman Ferry, at east corner of Huffman's house, nail in root of tree at	1,011.75
38.5	Surface of water	961
38.7	Head of shoals, surface of water	959
40.7	At mouth of creek on south, head of shoals, surface of water	957
40.7	Foot of shoals, surface of water	956
41.2	Head of large island, head of shoals, surface of water	955
41.2	Between island and north bank of river, foot of shoals, surface of water	955
41.4	Foot of island, head of shoals, surface of water	955
41.4	Foot of shoals, surface of water	955
41.6	Lovelady Ford, at head of small island between large island and south bank, head of shoals, surface of water	954
41.8	Lovelady Ford, north bank of river, surface of water	953
41.9	Foot of large island at foot of shoals, surface of water	951
43.6	County Ferry, 200 feet south of; west side of road, nail in box alder	968.8
43.6	Surface of water	948
43.8	Head of shoals, surface of water	947
43.8	Foot of shoals, surface of water	947
44.5	Head of shoals, surface of water	947
44.5	Foot of shoals, surface of water	[b] 946

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[a] Upper Morganton Bridge line adjusted to Morganton, Burke County court-house, extreme northwest corner of north portico, bronze tablet marked "1182;" elevation, 1,180.774 feet.

[b] Connelly Springs, 142.4 feet north of north rail of main track, James Hudson's brick store, south front, near east corner, bronze tablet marked "1193;" elevation, 1,191.762 feet.

Johnson Mill Creek flows into Catawba 1.6 miles below County Ferry, south side of river.

NOTE.—Water-surface elevations adjusted to mean gage reading 1.8 feet at Upper Morganton Bridge Elevation of 1.8-footmark, 996.3 feet.

TALLULAH RIVER BELOW BLALOCK, GA.

Tallulah River rises in Habersham and Rabun counties, Ga., flows in a southeasterly direction, and joins Chattooga River a little below Tallulah Falls, thus forming Tugaloo River. During August, 1903, this river was surveyed between Tallulah Falls, Ga., and the mouth of Persimmon Creek, near Blalock, Ga. The distance between these points is about 33 miles, and there is a fall of 451 feet. The survey consisted of a line of primary levels based upon the United States Geological Survey bench mark at Tallulah Falls, and a plane-table survey of the course of the river. The field sheets were plotted on a scale of 1:22,500, 30 bench marks were established, and 69 water-surface elevations obtained.

Tallulah River is a typical mountain stream and is subject to sudden freshets. As the Chattooga is of the same character the Tugaloo is a dangerous stream, a rise of 1.6 feet per hour for three consecutive hours being recorded on March 23, 1903, at the Southern Railway bridge near Toccoa, Ga. On this occasion the river rose 15.2 feet in eighteen hours.

Tallulah River crosses the fall line at Tallulah Falls, Ga. In this vicinity is some of the most picturesque and rugged scenery in the Southern States. In 3 miles the river drops from 1,415 to 755 feet above sea level, or a distance of 660 feet. The principal falls, in the order in which they occur, are L'eau D'or, 28 feet; Tempesta, 76 feet; Hurricane, 89 feet; Oceana, 41 feet; Bridal Veil, 17 feet—all in a distance less than three-fourths of a mile. On either bank are precipitous cliffs, rising in some places 500 feet sheer. The gorge continues to the Tugaloo, with the exception of one place about one-half mile long, where it opens up and forms what is known as the Old Valley farm. On either side the country is covered with woods, but not a great deal of merchantable timber appears to be available.

In 2 miles, above Tallulah Falls, the river has a fall of 110 feet. At the head of this fall the bottom widens into a valley which appears to be an excellent basin for storing water. Three and one-fourth miles farther upstream at an unnamed shoal with a 12-foot fall, there is a fair site for a dam. The bottom is rocky, and there are steep hills on either side.

Five miles farther upstream is a shoal with a 25-foot fall, steep hills on either side, and hard rock bottom. Just above Denton Ford is a 23-foot shoal about three-fourths of a mile long where there is a splendid site for a dam.

The fall in the lower Tallulah below the falls is about 250 feet. A large portion of this fall can be used for power without interfering with the resort at Tallulah Falls. By installing an electrical plant at the upper end of Old Valley farm a good power could be obtained.

The elevations in the following list are based upon the elevation of a bronze tablet in rock 70 feet east of the public road and 20 feet south of Tallulah Falls, station marked "1569 Atlanta." This elevation is accepted as 1,568.302 feet above mean sea level in accord with the 1903 adjustment of the precise-level net. The line is corrected to accord with primary work at mouth of river and at Burton.

The leveling was done in 1903, under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

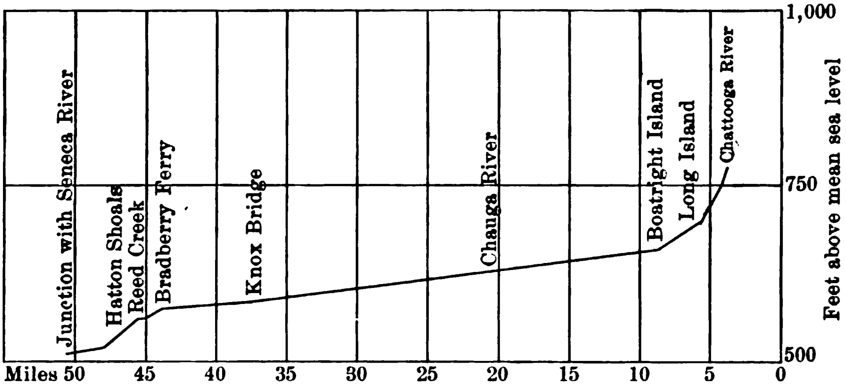


FIG. 2.—Profile of Tallulah River below Blalock, Ga.

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.

Distance.		Elevation in feet
0.0	Junction of Chattooga and Tallulah rivers, surface of water	754
.0	100 feet north of junction rivers, edge of river, point on rock	761.29
.0	200 feet north of junction rivers, west side of Tugaloo River, gum tree, nail in root of	762.65
.2	Chattooga River, 500 feet north of, west side of Tallulah River, nail in root of oak stump	769.46
.3	Surface of water	767
.4	Mouth of small stream, surface of water	782
.6	150 feet west of river	799.86
.9	Surface of water	818
1.3	Surface of water	848
1.6	Surface of water	878
1.7	Surface of water	893
1.8	Surface of water	911
2	Foot of rapids, surface of water	935
2.1	Middle of rapids, surface of water	944
2.2	Head of rapids, surface of water	947
2.2	Foot of rapids, surface of water	954
2.25	Surface of water	964

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.—Cont'd.

Distance in miles.		Elevation in feet.
2.3	Foot of small falls, surface of water	981
2.35	Foot of rapids, surface of water	987
2.38	300 feet below bend, head of rapids, surface of water	980
2.4	Surface of water	997
2.5	Surface of water	1,008
2.6	Bridal Veil Falls, foot of, surface of water	1,022
2.6	Head of falls, surface of water	1,039
2.65	Surface of water	1,057
2.8	Oceana Falls, foot of, surface of water	1,074
2.85	Head of falls, surface of water	1,115
3.1	Hurricane Falls, foot of, surface of water	1,140
3.1	Head of Hurricane Falls, surface of water	1,229
	Tempesta Falls, foot of, surface of water	1,246
3.1	Tempesta Falls, head of, surface of water	1,322
3.2	L'eau d'or Falls, foot of, surface of water	1,322
3.2	L'eau d'or Falls, head of, surface of water	1,350
3.3	Surface of water	1,379
3.4	Surface of water	1,396
3.6	Clayton Road iron highway bridge, surface of water	1,414
	Tallulah Falls station, 70 feet east of public road, 20 feet south of station, in rock, bronze tablet marked "1569 Atlanta"	1,568.302
3.6	Tallulah Falls, 0.5 mile northeast of; at forks of road, 50 feet south of bridge over river	1,457.92
3.6	Clayton Road iron highway bridge, 0.5 mile north of Tallulah Falls, floor of	1,441.87
	Surface of water	1,419
	Opposite stone pier railroad bridge, surface of water	1,439
	Surface of water	1,449
	On rock, surface of water	1,459
4.9	Foot of falls, surface of water	1,486
4.9	Top of falls, surface of water	1,492
5.1	Surface of water	1,509
5.5	Head of island, surface of water	1,530
5.6	20 feet west of Tallulah Falls Railroad, point on top of rock	1,538.21
5.6	Surface of water	1,529
6	Surface of water	1,538
6.5	Surface of water	1,553
6.6	Surface of water	1,559
7.3	150 feet east of river, in cornfield, dead apple tree, nail in root of	1,579.23
7.3	Surface of water	1,569
8.4	Surface of water	1,573

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.—Cont'd.

Distance in miles.		Elevation in feet.
8.6	Surface of water	1,578
8.7	65 feet north of river, in cornfield, walnut tree, nail in root of	1,589.25
8.7	Surface of water	1,578
9.6	Tiger Creek, on point of land between river and creek, burnt poplar tree, nail in side of	1,590.30
9.6	Surface of water	1,584
9.9	Surface of water	1,589
10	5 feet west of river, in footpath, point on sharp rock	1,595.59
10.2	Surface of water	1,592
10.4	Surface of water	1,596
10.5	10 feet west of river, nail in root of beech tree	1,601.32
10.6	Surface of water	1,600
10.9	Surface of water	1,603
11.8	Crane Ford, 150 feet west of, apple tree, nail in root of	1,620.33
11.8	Surface of water	1,607
12.1	Surface of water	1,610
13.3	Dockens Ford, 12 feet west of river, nail in side of dead tree	1,623.06
13.3	Surface of water	1,615
13.8	Ellord Ford, 150 feet east of, at bend of, poplar tree, nail in side of	1,634.36
13.8	Surface of water	1,621
14.4	Surface of water	1,626
14.5	Surface of water	1,628
14.6	Eden Church, 150 feet west of, 150 feet east of river, nail in root of large red-oak tree	1,649.41
15.6	Taylor Shoals, 10 feet west of river, middle of, point on large flat rock	1,644.90
15.6	Surface of water	1,641
16.2	Surface of water	1,648
16.5	Surface of water	1,657
16.6	Surface of water	1,657
17.7	James Smith boat landing, 2 feet west of river, nail in stump	1,670.53
18.4	Fall Creek, mouth of, surface of water	1,669
18.6	Jones Ford, 6 feet south of river, slanting persimmon tree, nail in side of	1,677.33
18.6	Surface of water	1,674.6
19.2	Flat Creek, mouth of, surface of water	1,681
20.6	Surface of water	1,687
20.9	Cliff Creek, mouth of, surface of water	1,690
21.4	Surface of water	1,697
21.5	Denton Ford, 10 feet west of river, nail in root of pine tree	1,703.61
21.5	Surface of water	1,701
21.8	Mouth of small stream, surface of water	1,703
21.9	Seal Creek, mouth of, foot of double shoals, surface of water	1,704

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.—Cont'd.

Distance in miles.		Elevation in feet.
22	Surface of water	1,707
22.3	Middle of shoals, surface of water	1,714
22.6	Crow Ford, 100 feet south of, 10 feet south of river, twin hemlock tree, nail in root of	1,725.93
22.6	Surface of water	1,724
22.7	Scarecrow Creek, mouth of, surface of water	1,727
24	George Creek, mouth of, surface of water	1,737
24.5	Bridge Creek, mouth of, surface of water	1,738
25	In shoals, surface of water	1,747
25.1	—— Ford, surface of water	1,749
25.1	At above ford, south edge of river, point on rock	1,750.29
25.6	Rocky Ford, 10 feet south of, dead hemlock tree, nail in root of	1,758.47
25.6	Surface of water	1,756
25.9	Surface of water	1,757
26.2	Kenny Creek, mouth of, surface of water	1,760
26.3	Fuller Ford, surface of water	1,760
26.4	Fuller Ford, 500 feet northwest of, point on rock	1,762.62
27	Surface of water	1,767
27.3	Cannon Ford, 75 feet southwest of, nail in root of white oak	1,781.97
27.3	Surface of water	1,769
28.2	—— Ford, west side of, nail in root of red gum tree	1,777.87
28.2	Surface of water	1,774
28.5	Wildcat Creek, 50 feet southwest of, west side of road, point on rock	1,783.19
28.5	Surface of water	1,776
29.3	Surface of water	1,785
29.5	Surface of water	1,787
29.6	Dicks Creek, surface of water	1,789
30.1	Burton, 12 feet southwest of bridge, nail in root of maple tree	1,794.96
30.1	Floor of bridge	1,806.4
30.1	Surface of water	1,790
30.1	High-water mark	1,804
30.2	Burton, 1,000 feet above bridge, 15 feet east of river, 10 feet west of road, bronze tablet marked "———"	1,795.140
32.1	12 feet west of ford, nail in side of ash tree	1,819.04
32.1	Surface of water	1,813
32.4	Surface of water	1,819
32.7	Murford, 100 feet southwest of, nail in west side of white-oak tree	1,838.05
32.7	Surface of water	1,824
33	Rocky Ford, surface of water	1,829
33.1	Shallow Ford, 500 feet southeast of, in road, point on rock	1,841.48
33.2	Surface of water	1,835

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.—Cont'd.

Distance in miles.		Elevation in feet.
33.6	Deep Ford, 30 feet south of, nail in side of sycamore tree	1,842.39
33.6	Surface of water	1,839
34.3	Popcorn Creek, mouth of, surface of water	1,849
35	Deep Ford, 3 feet east of, nail in side of beech tree	1,862.03
35.8	Persimmon Creek, 75 feet east of river, 30 feet south of creek, nail in side of hickory tree	1,881.67

TUGALOO RIVER BELOW TALLULAH FALLS, GA.

Tugaloo River, which flows in a southeasterly direction between Georgia and South Carolina, is a continuation of Savannah River, and extends from the mouth of Seneca River to the mouth of Chattooga River. The bed of the stream is in Georgia. The survey of this river covered a distance of 50½ miles. It connected with the survey of Savannah River at Andersonville, and extended past the mouth of the Chattooga along the Tallulah as far as Tallulah Falls. The primary levels were based upon the United States Geological Survey bench mark at Parkesville, Ga. Nine bench-mark tablets and 64 temporary bench marks were established, and 98 water-surface elevations were obtained. The plane-table sheets were plotted on a scale of 1:22,500 for that portion of the survey above the mouth of the Chattooga; from that point to Owens Shoals the scale was 1:45,000; between Owens Shoals and Andersonville it was 1:22,500.

From the head of the Tugaloo to a point about one mile above the mouth of Panther Creek the banks are very steep, but are not so marked as along the Tallulah, except in some places where there is a cliff on one side. Below the point above mentioned the bottom is from one-fourth to three-fourths mile wide in most places, the soil being very fertile and in a high state of cultivation. Cotton is the main crop, with corn next, wheat, rye, sugar cane, etc., combined making but a small percentage of the yield. The timber is very scattered.

The elevations in the following list are based on an aluminum tablet marked "1050 M. C." at Washington street entrance to the State capitol at Atlanta, the elevation of which is now accepted as 1,049.546 feet above mean sea level. The initial point upon which these levels depend is a bronze tablet at north side of east entrance at court-house at Clarksville, Ga., marked "1373 Atlanta," the elevation of which is accepted as 1,371.991 feet above mean sea level, in accord with the 1903 adjustment of the precise-level net.

The leveling was done in 1903 under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

All permanent bench marks are marked with the letters "Atlanta" in addition to the figures of elevation.

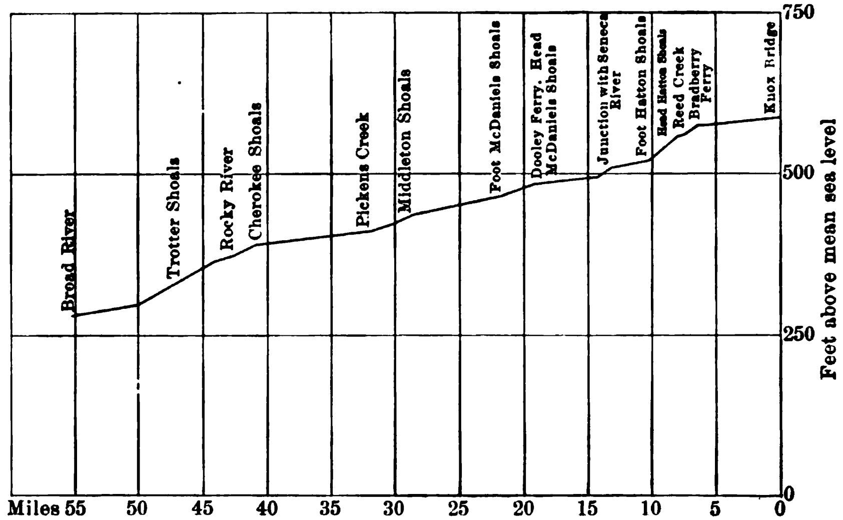


FIG. 3.—Profile of Tugaloo River below Tallulah Falls, Ga.

Elevations from Clarksville, via Turnerville, to Tallulah Falls, Ga.

	Elevation in feet
Clarksville, Habersham County court-house, north side of east entrance, bronze tablet marked "1373 Atlanta"	1,371.991
Clarksville, 0.7 mile southeast of, west side of road, nail in root of oak tree	1,436.353
Clarksville, 2 miles east of, south of track, nail in root of old stump	1,444
Clarksville, 1.5 miles east of station, dogwood tree, nail in root of	1,457.576
Clarksville, 2.5 miles east of, at railroad crossing, south of track, oak tree, nail in root of	1,419.40
Clarksville, 4.5 miles east of, oak stump, nail in root of	1,440.16
Clarksville, 6 miles east of, nail in root of oak tree	1,513.52
Clarksville, 7.5 miles east of, nail in root of oak tree	1,475.66
Turnerville station, 30 feet north of, nail in root of cottonwood tree	1,542.98
Turnerville, 1.9 miles northeast of, south of track, nail in root of oak tree	1,590.48
Turnerville, 3.2 miles northeast of station, nail in stump of gum tree	1,588.65
Turnerville, 4 miles northeast of, at road crossing east of track, nail in root of persimmon tree	1,612.33
Tallulah Lodge, 40 feet east of track, nail in side of hickory tree	1,605.84
Tallulah Falls station, 20 feet south of, 70 feet east of public road, rock, bronze tablet marked "1569 Atlanta"	1,568.302
Tallulah Falls, 0.5 mile north of east of, at forks of road, 50 feet south of bridge over river	1,457.92

Elevation from point 2 miles south of Tallulah Falls south down Tugaloo and Savannah rivers to mouth of Broad River, Lisbon, Ga.

	Elevation in feet.
Turnerville, 3.2 miles east of station, nail in stump of gum tree	1,588.65
Turnerville, 4.3 miles east of, nail in root of oak tree	1,504.20
Turnerville, 4.4 miles east of, nail in root of pine tree	1,386.10
Turnerville, 5.1 miles east of, south of road, point on rock	979.72

Elevations on Tugaloo River below Tallulah Falls.

Distance in miles.		Elevation in feet.
0.0	Junction of Tallulah and Chattooga rivers, 200 feet northwest of, gum tree, west side of Tallulah River, nail in root of gum tree	762.65
.0	Junction of rivers, 100 feet northwest of; edge of river, point on rock	761.29
.0	Junction of Tallulah and Chattooga rivers, water surface	754
.0	Tugaloo River, head of, pine tree, nail in root of	728.86
.7	Island, head of, surface of water	723
.8	Surface of water	711
2	Surface of water	698
2	West side of river, point on rock	698.79
2.1	Surface of water	690
2.4	Surface of water	686
2.8	Hickory tree, nail in root of	690.51
2.8	Surface of water	684
2.9	Surface of water	681
3.1	Small stream, mouth of, surface of water	674
4.4	Panther Creek, mouth of, surface of water	669
4.4	Panther Creek, 600 feet south of mouth and 50 feet west of river, west edge of public road, in large rock, bronze tablet marked "715 Atlanta"	713.793
5.3	Surface of water	667
5.4	Deaton Ford, surface of water	666
5.4	Small bridge, surface of water	664
5.4	Walnut tree, nail in root of	676.45
6.3	Surface of water	659
6.4	Small creek, South Carolina side, mouth of, surface of water	655
7.4	Walnut tree, 100 feet west of river, nail in root of	664.87
7.5	Small boat landing, surface of water	652
8	Big John Creek, mouth of, surface of water	650
8.9	Prather's bridge, 100 feet northwest of river and old bridge, cottonwood tree, nail in side of	659.02
8.9	Surface of water	648
9.9	James Prather homestead, middle step front entrance, bronze tablet marked "728 Atlanta"	726.873

Elevations on Tugaloo River below Tallulah Falls—Continued.

Distance in miles.		Elevation in feet.
10.5	Stream, mouth of, surface of water	646
11.5	Surface of water	644
11.5	Apple tree, 600 feet west of river, nail in root of	657.40
13	Stream, mouth of, surface of water	642
13	Gum tree, 10 feet west of river, nail in root of	658.51
13.8	Gum tree, west edge of river, nail in root of	651.33
13.8	Toccoa Creek, mouth of, surface of water	641
13.9	Jarrett Bridge, surface of water (during flood Mar. 21, 1903)	642.5
15.4	Water oak tree, 4 feet east of river, nail in root of	642.50
15.4	Walnut tree, 50 feet west of railroad bridge, nail in root of	660.52
15.4	Railroad bridge crossing Tugaloo River, west abutment, bronze tablet marked "666 Atlanta"	665.467
15.4	Stream, mouth of, surface of water	640
16.4	Stream, mouth of, surface of water	639
16.5	Sycamore tree, 50 feet south of river, nail in root of	641.09
16.5	Stream, mouth of, surface of water	637
17.5	50 feet east of river, birch tree, nail in root of	646.91
18	Surface of water	636
18	200 feet east of county road, 100 feet west of river, walnut tree, nail in root of	648.60
19	Saw mill, mouth of stream opposite, surface of water	632
19.1	Walnut tree, nail in root of	647.65
20.1	Stream, mouth of, surface of water	630
21.3	Swamp bush, 3 feet northwest of river, nail in top of	634.60
21.7	Rock Creek, 10 feet south of, walnut tree, nail in root of	640.35
21.7	Surface of water	624
22	Jenkins Ferry, 400 feet northwest of, 200 feet west of river, walnut tree, nail in root of	638.10
22	W. J. Perkins homestead, north side of house, in chimney, 2 feet above ground, bronze tablet marked "732 Atlanta"	[a] 730.754
22	Surface of water	624
22	High water	638
22.3	Stream, mouth of, surface of water	622
22.4	Walnut tree, nail in stump	635.56
22.6	Walnut tree, 40 feet west of river, nail in root of	634.32
23.2	Birch tree, on edge of small stream, nail in root of	629.55
24.5	Surface of water	618
24.5	Small tree, 4 feet west of river, nail in root of	619.47
25.1	Surface of water	616
25.5	Pine tree, 50 feet west of river, nail in root of	625.12
25.7	Surface of water	614

[a] The above is on a single spur line.

Elevations on Tugaloo River below Tallulah Falls—Continued.

Distance in miles.		Elevation in feet.
26.1	Old stump, 41 feet west of river, nail in	615.42
26.3	Head of Shelor Shoals, surface of water	610
27.6	Walnut tree, 10 feet north of river, nail in root of	614.54
27.6	Surface of water	607
27.9	Surface of water	605
28.1	Large creek, mouth of, surface of water	604
29.1	Pine tree, 5 feet northeast of river, nail in top of	623.27
29.3	Shelor Ferry, water oak tree, 10 feet northeast of river, nail in root of	606.46
29.3	Surface of water	600
29.3	Shelor Ferry, 0.3 mile southwest of; 100 feet northwest of I. E. Martin's house, 10 feet north of road, in large rock, bronze tablet marked "630 Atlanta"	628.875
30.1	Stream, mouth of, surface of water	599
30.3	Sycamore tree, 10 feet north of river, nail in root of	601.17
30.3	Mouth of stream, near bend in river, surface of water	597
30.4	Water oak stump, 10 feet north of river, nail in root of	598.10
30.4	Surface of water	595
31.8	Gum Log Creek, mouth of, surface of water	592
32.3	Near Middle Branch, apple tree, nail in root of	597.79
32.4	Surface of water	590
33.1	Surface of water	588
33.6	Knox Bridge, 100 feet west of, in fork of road, maple tree, nail in root of	602.73
33.6	Knox Bridge, 200 feet west of S. A. Glenn's house, in chimney, bronze tablet marked "613 Atlanta"	612.241
33.6	Surface of water	588
34.3	Surface of water	587
34.3	25 feet northwest of Shoal Creek, dead stump, nail in top of	598.34
35.3	Shoal Creek, mouth of, surface of water	586
35.3	Pine stump, 200 feet north of river, nail in top of	601.72
35.4	Knox Branch, mouth of, surface of water	586
36.1	Oak tree, 900 feet north of river, nail in root of	591.83
36.5	Burton Branch, mouth of, surface of water	582
37.5	South side of river, point on bottom of cliff	588.07
37.8	Pullins Ferry, 250 feet south of, 10 feet north of road, red oak tree, nail in root of	596.59
37.8	Pullins Ferry, surface of water	581
38.4	Cleveland Shoals, head of, surface of water	578
39.6	Averys Ferry, sycamore tree 10 feet north of river, nail in root of	584.36
39.6	Foot of shoals, surface of water	578
39.8	Bottom of cliff, 2 feet south of river, point on rock	581.95

Elevations on Tugaloo River below Tallulah Falls—Continued.

Distance in miles.		Elevation in feet.
39.8	Averys Ferry, 20 feet south of river, top of cliff, in rock, bronze tablet marked "588 Atlanta"	587.443
40.3	Bradberrys Ferry, walnut tree 100 feet south of river, nail in root of	581.95
40.3	Chandlers Shoals, head of, surface of water	575
40.7	Bottom of cliff, 1 foot south of river, point on rock	577.26
40.8	Beech tree, 1 foot south of river, nail in root of	572.24
40.8	Surface of water	570
40.9	Reed Creek, mouth of, surface of water	564
41.1	Foot of Chandlers Shoals, surface of water	562
41.4	Reed Creek, 900 feet east of 10 feet south of river, nail in stump	566.95
41.7	Boat landing, birch tree, nail in root of	563.72
42.3	Hatton Shoals, head of, surface of water	560
42.8	North edge of river, F. Clark's house, 1,000 feet south of, nail in root of maple tree	556.79
42.8	Surface of water	555
43.3	Big Beaverdam Creek, 25 feet east of, nail in root of beech tree	554.01
43.3	Surface of water	546
43.7	Large pine tree, 25 feet east of small stream, 5 feet north of river, nail in root of	537.07
43.7	Surface of water	535
44.2	Hatton Ford, bottom of cliff, point on rock	526.91
44.2	Surface of water	525
44.5	Mouth of branch, surface of water	522
44.7	Mouth of branch, surface of water	519
45.3	Water oak tree, 30 feet northeast of river, nail in root of	529.36
46.3	Beech tree, 15 feet east of river, nail in root of	525.17
46.3	Surface of water	519
46.6	Burnt stump, 40 feet east of river, nail in top of	524.70
46.6	Surface of water	518
47.7	Andersonville, S. C., 0.5 mile north of, twin beech tree 15 feet north of river, nail in root of	522.27
47.8	Mouth of branch, surface of water	516
48.2	Foot of rapids, surface of water	511
48.2	Andersonville, S. C., east side of road, 200 feet east of river, northwest of Little Broadway Creek, in rock, bronze tablet marked "538 Atlanta"	537.519
48.2	"Brouris" Ferry, surface of water	510
48.2	20 feet west of river, point on rock	514.45

SAVANNAH RIVER FROM ANDERSONVILLE, S. C., TO LISBON, GA.

Savannah River, which flows between Georgia and South Carolina, is formed by the junction of Seneca and Tugaloo rivers at Andersonville, Anderson County, S. C. Tugaloo River is in turn formed by the junction of Tallulah and Chattooga rivers at a point about 3 miles below Tallulah Falls, Georgia.

Savannah River proper flows in a southeasterly direction through a rather hilly country, which is chiefly devoted to the production of cotton and corn. On the lowlands these crops are sometimes damaged by high water. The river contains many small islands, some of which are in a high state of cultivation.

During April and May, 1903, a survey of Savannah River between Andersonville, S. C., and the mouth of Broad River, near Lisbon, Ga., a distance of 42 miles, was made by Carroll Caldwell, field assistant. In the above distance there is a fall of 219 feet. The primary levels for this survey were based on the United States Geological Survey bench mark at Andersonville, S. C. Field sheets were plotted on the scale of 1:22,500, and during the course of the survey 7 tablets and 62 temporary bench marks were established, 91 water-surface elevations determined, and the following possible powers noted.

The first shoal of importance is the McDaniels Shoal, where there is a fall of 19 feet in 2½ miles. Half a mile above the foot of the shoal and at the head of Harper Island is an excellent site for a dam about 700 feet long.

At Turners Shoals there is a fall of 17 feet in about 2½ miles. These shoals begin at Kenly Ferry and extend to Craft Ferry. The river widens considerably about a mile below Kenly Ferry and has several good sites, one being on Craft Island. These shoals could be developed only at considerable expense, as a dam would have to be 1,000 feet long.

Half a mile below, the Middleton Shoals have a fall of 11 feet in 1¼ miles and offer an excellent site for a dam. The bottoms and sides are of rock.

One mile below are Gregg Shoals with a 7-foot fall in about a mile. Here the river runs between steep hills and a dam would be about 900 feet long.

Half a mile below Moseley Ferry are the Cherokee Shoals, having a fall of 18.9 feet in less than 3 miles. This is a very fine power site, as the river runs between steep hills. A dam would be about 1,000 feet long and would be placed one-fourth of a mile above the Seaboard Air Line bridge.

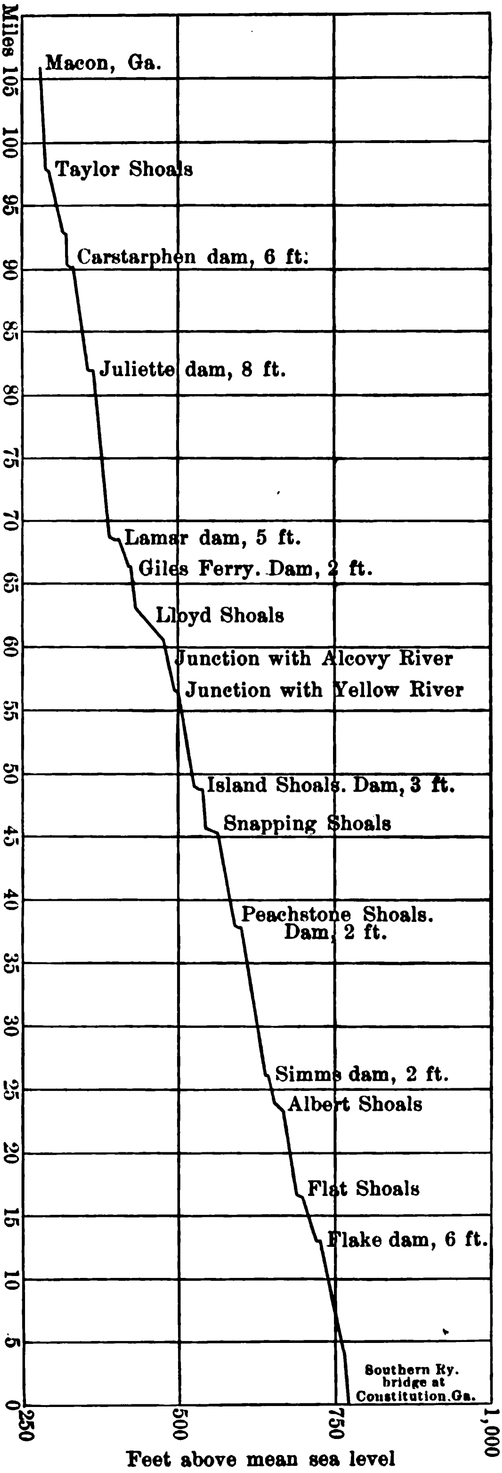
One and one-fourth miles below the bridge are Trotters Shoals with a fall of 69 feet in 6 miles. These are considered the finest shoals on the river. They commence at the foot of Watkins Island and run below Tates mill to Coffee Creek. In this distance there are numerous rocky bluffs where there are excellent dam sites.

From the foot of Trotters Shoals to the mouth of Broad River, the end of the survey, there is a uniform fall of 3 feet per mile.

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.[a]

Distance in miles.		Elevation in feet.
48. 2	Andersonville, S. C., east side of road, 200 feet east of river, northeast of Little Broadway Creek, bronze tablet marked "538 Atlanta"...	537. 519
48. 7	Seneca River, mouth of, surface of water..........................	505
48. 7	Small pine tree, nail in root of..........................	512. 60
49. 3	Branch, mouth of, surface of water..........................	501
49 3	Sycamore tree on edge of branch and river, nail in root of.........	502. 78
50. 5	Creek, mouth of, surface of water..........................	497
50. 6	Opposite island, 50 feet west of river, willow stump, nail in top of.	503. 38
50. 7	Branch, mouth of, surface of water..........................	493
51. 4	In footpath, 10 feet west of river, large red oak tree, nail in root of.	499. 76
51. 4	Lightwood Log Creek, 400 feet west of river, tripple water oak tree.	507. 28
52. 3	Carters Ferry, surface of water..........................	492
52. 3	High water..........................	516
52. 3	Lightwood Log Creek, mouth of, surface of water..........................	491
52. 8	60 feet west of river, large walnut tree, nail in root of..........................	501. 09
53. 3	Browns Ferry, 40 feet west of, double water oak tree, nail in root of.	497. 79
53. 3	Surface of water..........................	488
53. 3	High water..........................	499
53. 3	Browns Ferry, 1,200 feet northeast of O. C. Brown's house, in brick and stone abutment at rear of, northwest corner, bronze tablet marked "518 Atlanta"..........................	516. 891
54. 6	Powderbag Creek, mouth of, surface of water..........................	487
54. 8	Creek, 520 feet south of, 30 feet west of river, box elder tree, nail in root of..........................	491. 88
55	Dooley Ferry, 114 feet west of river, poplar tree, nail in root of...	492. 64
55	Surface of water..........................	486
55. 7	Craft Island, opposite, hanging over edge of river, maple tree, nail.. in root of..........................	485. 13
55. 7	Surface of water..........................	485
55. 7	Long Branch, mouth of, surface of water..........................	484
56. 1	30 feet south of river, large poplar tree, nail in root of..........................	487. 61
56. 1	Surface of water..........................	482
56. 1	McDowells Shoals, head of, surface of water..........................	477
56. 1	High-water mark..........................	487
56. 8	70 feet southwest of river, pine tree, nail in root of..........................	483. 26
56. 8	Surface of water..........................	474

[a] Continued from Tugaloo River elevations. See p. 28.



PROFILE OF SAVANNAH RIVER FROM ANDERSONVILLE, S. C., TO LISBON, GA.

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.—Continued.

Distance in miles.		Elevation in feet.
57.3	Turner Creek, mouth of, southwest of river, birch tree, nail in root of.	473.43
57.3	Surface of water	471
57.5	20 feet southwest of river, birch tree, nail in root of	476.13
57.5	Surface of water	470
58	Harper Island, 0.1 mile west of, red oak tree bending over edge of river, nail in root of	472.57
58.7	Surface of water	466
59.1	Parks Ferry, 0.2 mile above, west side of ferry road, opposite colored house, foot of steep hill, in cliff, bronze tablet marked "495 Atlanta"	494.435
59.3	Parks Ferry, 15 feet west of river, large red oak tree, nail in root of.	468.53
59.3	Surface of water	461
59.5	Surface of water	460
60.5	Mulberry tree stump, west side of river, nail in root of	462.42
60.5	Surface of water	458
60.8	Saddlers Old Ferry, 40 feet west of river, rock cliff, point on rock.	466.598
60.8	Surface of water	458
60.9	60 feet south of river, hickory tree, nail in root of	471.27
60.9	Surface of water	457
61.5	Cedar Creek, 500 feet north of river, large black oak tree, nail in root of	460.66
61.5	Cedar Creek, mouth of, surface of water	455
62.3	Kinleys Ferry, 0.1 mile southwest of; 10 feet west of river, white ash tree, nail in root of	457.68
62.3	Surface of water	454
62.4	Turners Shoals, head of, surface of water	453
62.5	McMullins Branch, mouth of, surface of water	450
64.2	50 feet south of river, small hickory tree, nail in root of	456.55
64.3	Shoals, surface of water	450
65.8	200 feet west of river, black oak tree, nail in root of	459.62
65.9	Surface of water	443
66.2	25 feet west of river, black oak tree, nail in root of	445.80
66.2	Surface of water	440
66.9	Craft Ferry, 10 feet west of river, red oak tree, nail in root of	443.67
66.9	Creek, mouth of, surface of water	437
66.9	Craft Ferry, 125 feet west of boat landing, 60 feet west of river, in rock, aluminum tablet marked "450 Atlanta"	449.306
66.9	Foot of Turners Shoals, surface of water	437
68.1	Middleton Shoals, head of, surface of water	435
68.5	Barnes Island, opposite, 125 feet west of river, small black oak tree, nail in root of	443.11
68.5	Surface of water	431
68.7	300 feet west of river, on top of cliff, dogwood tree, nail in root of.	457.46

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.—Continued.

Distance in miles.		Elevation in feet.
69.5	West edge of river, willow stump, nail in root of	428.03
69.8	Middleton Shoals, foot of, surface of water	424
69.8	20 feet west of river, post-oak tree, nail in root of	432.50
70.2	Powells Ferry, 20 feet west of river, water oak tree, nail in root of.	435.23
70.2	Powells Ferry, surface of water	422
70.9	Surface of water	419
71	Powells Ferry, 0.8 mile south of, 150 feet west of river, white ash stob, nail in top of	439.30
71.3	Gregg Shoals, head of, surface of water	418.7
72.4	Black Ferry, 25 feet west of river, nail in root of birch tree	421.677
72.4	Black Ferry, surface of water	410.3
72.8	350 feet east of river, octagon burnt tree stump, nail in root of	431.08
73.2	Creek, mouth of, surface of water	409
73.4	350 feet east of river, persimmon tree stump, nail in root of	419.39
73.7	Branch, mouth of, surface of water	407
73.7	Mill, opposite, surface of water	406
73.8	Coldwater Creek, mouth of, surface of water	406
74.3	350 feet east of river, 140 feet southwest of small branch, persimmon tree, nail in root of	414.39
75.8	Allens Creek, mouth of, surface of water	404
76.2	Harper Ferry, 20 feet east of river, southside of road, water oak tree, nail in root of	412.26
76.2	Surface of water	403
76.2	High-water mark	416
76.4	250 feet southeast of W. J. Taylor's house, side of brook, in limestone rock, bronze tablet marked "420 Atlanta"	419.146
77	Branch, mouth of, surface of water	402
77.3	Ruckers and Tuckers Ferry, 40 feet southeast of and 5 feet west of river, willow tree, nail in side of	405.49
77.3	Surface of water	401
77.3	High-water mark	418
77.6	Surface of water	400
78.1	Surface of water	399
78.4	English Creek, 60 feet west of, 50 feet north of river, white hickory stump, nail in root of	417.13
78.4	English Creek, mouth of, surface of water	398
78.9	McCauleys Island, 900 feet south of head of, surface of water	397
79.2	McCauleys Ferry, 40 feet west of river, ash stump, nail in root of	407.19
79.2	Surface of water	397
79.6	Surface of water	396
79.6	150 feet north of river, beech tree, nail in root of	407.39
80.5	Branch, mouth of, surface of water	395
80.8	Surface of water	394

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.—Continued.

Distance in miles.		Elevation in feet.
80.8	50 feet east of river, walnut tree, nail in root of	398.77
81	Moseley Ferry, 50 feet east of river, walnut tree, nail in root of	400
81	Surface of water	392
81.3	Surface of water	392
81.6	Surface of water	391
81.7	Large falls, head of, surface of water	390
81.8	50 feet east of river, twin pine tree, nail in root of	399.23
81.9	Cherokee Shoals, surface of water	388
82.6	Surface of water	379
82.6	125 feet east of river, oak tree, nail in root of	385.75
83.2	Surface of water	374
83.3	Carter Island, ferry, 40 feet west of river, white oak tree, nail in root of	382.52
83.5	Surface of water	373
83.7	Rocky River, mouth of, surface of water	372
84.2	Surface of water	371
84.2	Seaboard Air Line bridge, abutment, east side of bridge, bronze tablet marked "383 Atlanta"	382.161
85.1	Watkins Island, lower end of, 15 feet north of river, oak tree, nail in root of	375.7
85.2	Watkins Island, 150 feet southwest of, on mainland, dead stump, nail in side of	374.59
85.2	Trotter's shoals, head of, surface of water	367
85.5	Shoals, surface of water	364
85.7	Head of island, surface of water	362
85.9	Surface of water	358
86	75 feet west of river, nail in stub	367.4
86.2	Calhoun Island, end of, surface of water	356
86.3	60 feet southwest of river, black ash tree, nail in root of	365.01
86.3	Trotters Shoals, in, surface of water	353
86.6	Surface of water	351
86.6	Cliff, bottom of, on rock, point	354.27
87.1	Calhoun Ferry, triple cedar tree, 75 feet west of river, nail in root of	348.39
87.1	Surface of water	340
87.5	Surface of water	336
87.6	50 feet southwest of river, in path, pine tree, nail in root of	341.32
88.1	Creek, mouth of, surface of water	329.7
88.3	Surface of water	328
88.6	10 feet southeast of road, Spanish oak, 400 feet west of river, nail in root of tree	338.61
88.9	Surface of water	325
89.2	Surface of water	322

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.—Continued.

Distance in miles.		Elevation in feet.
89.2	200 feet west of river, on top of steep hill, in footpath, hickory tree, nail in root of	360.67
89.7	Calhoun Ferry, 2.5 miles southeast of, 50 feet west of river, in large bronze tablet marked "320 Atlanta"	319.252
89.4	Surface of water	318
89.7	Surface of water	313
90.1	Surface of water	308
90.2	Surface of water	304
90.3	10 feet west of river, 300 feet north of old mill, water oak, nail in root of	305.90
90.3	Surface of water	301
90.4	Surface of water	299
91.3	Branch, mouth of, surface of water	292
91.3	10 feet west of river, dead birch tree, nail in root of	300.21
91.8	Surface of water	291
92.3	Creek, surface of water	289
92.8	Clarks Ferry, 200 feet west of river, water oak, copper tack in root	309.13
92.8	Surface of water	287
92.8	High-water mark	307
93.7	Creek, 1,500 feet below, surface of water	285
93.9	50 feet west of river, gum tree, copper tack in side of	299.66
94.2	Surface of water	284
96.1	Petersburg Ferry, east side of road, dead black gum, nail in root of	293.41
96.1	Broad River, mouth of, surface of water	281
96.2	South side of ferry road, water oak, nail in root of	295.77
96.4	Lisbon, in brick wall of R. L. Cade's store, bronze tablet marked "328 Atlanta"	327.85

CHATTOOGA RIVER BELOW RUSSELL, S. C.

Between July 19 and August 10, 1903, Chattooga River was surveyed from its mouth, near Tallulah Falls, Georgia, to Russell Bridge, near Russell, S. C., a distance of 30 miles. In that distance there is a fall of 809 feet. A line of secondary levels was run, based on a primary bench mark of the United States Geological Survey 3 miles below Tallulah Falls. The field sheets were plotted on the scale of 1:22,500, and during the course of the survey 23 bench marks were established and 97 water-surface elevations were noted.

Chattooga River contains many available undeveloped power sites. From its mouth to War Woman Creek, a distance of 22 miles, the river runs through a wild, rugged country, almost uninhabited. It flows in a gorge almost the entire distance and is very narrow and swift. There are numerous dam sites in this section, as the river is almost one continuous shoal and has an average fall of 33 feet to the mile, with a fine rock bottom and cliffs on either side. The rock is excellent for building purposes.

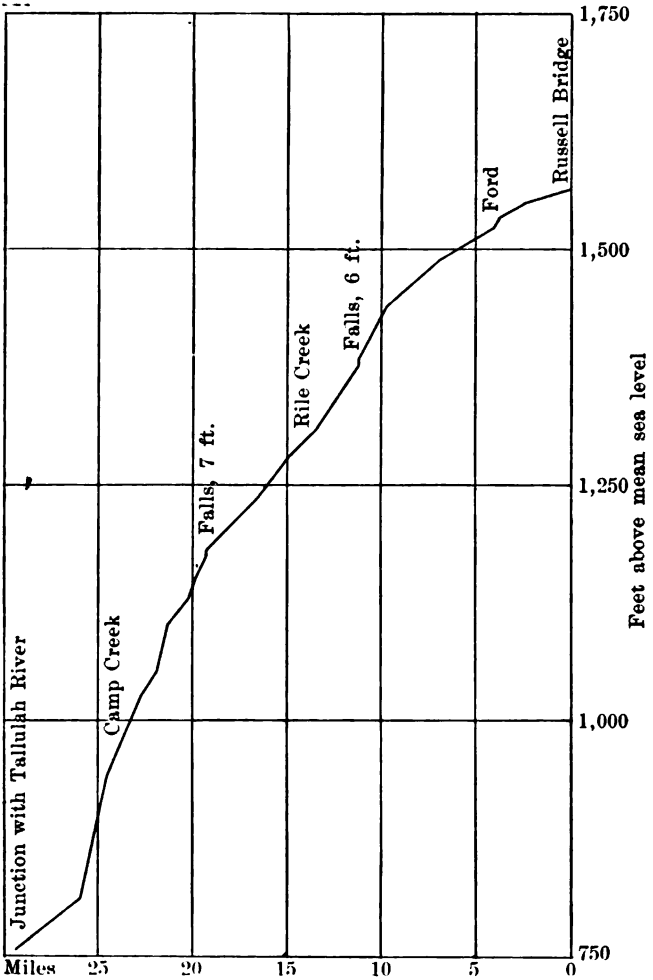


FIG. 4.—Profile of Chattooga River below Russell, S. C.

From War Woman Creek to Lone Bottom Ford, a distance of 5 miles, the bottoms widen considerably, and there are a few cultivated farms. Halfway, at Laurel Branch, there is an excellent site for a 12-foot dam, which would back water one-half mile without damage to cultivated lands. Here there is a good rock bottom and rocky bluffs on each side. From a half mile above Laurel Branch to Russell Bridge, the end of the survey, the bottoms are considerably wider and mostly cultivated.

The elevations in the following list are based on an aluminum tablet marked "1050 M C" at Washington street entrance to the State capitol at Atlanta, the elevation of which is now accepted as 1,049.546 feet above mean sea level. The initial point upon which these levels depend is a bench mark of primary levels of Tugaloo and Savannah River surveys at the mouth of Chattooga River. The elevations accord with the 1903 adjustment.

The leveling was done under the direction of Carroll Caldwell, field assistant, by Thomas B. O'Hagan, levelman.

Elevations on Chattooga River from its mouth to Russell Bridge, Ga., 0.7 mile north of Russell, S. C.

Distance in miles.		Elevation in feet.
0.0	Tallulah and Chattooga rivers, 100 feet north of junction, point on rock	761.29
.0	Tallulah and Chattooga rivers, white oak tree 75 feet west of junction of, 25 feet north of Tallulah River, nail in root of oak tree	762.21
.0	Surface of water	754
.2	Surface of water	759
.7	Mouth of stream, surface of water	763
1	Worse Creek, mouth of, surface of water	765
1.2	Surface of water	766
1.9	Small stream on north edge of river, Spanish oak, nail in root of	776.27
1.9	Surface of water	772
2.1	Surface of water	775
2.6	North side of river, point on rock	788.63
3	Surface of water	779
4	East side of river, point on rock	851.51
4	Surface of water	849
4.1	Surface of water	869
4.5	Creek, mouth of, surface of water	892
4.7	Surface of water	899
4.9	East side of river, point on rock	918.27
4.9	Surface of water	919
5	Surface of water	929
5.1	Surface of water	939
5.2	Surface of water	949
5.3	Mouth of stream, head of shoals, surface of water	954
5.6	Camp Creek, mouth of, surface of water	961
5.6	Trail Ford, point on rock 20 feet east of river	967.50
5.6	Trail Ford, surface of water	962
5.8	Surface of water	969

Elevations on Chattooga River from its mouth to Russell Bridge, Ga., 0.7 mile north of Russell, S. C.—Continued.

Distance in miles.		Elevation in feet.
6.1	Surface of water	979
6.3	Surface of water	989
6.7	Surface of water	999
7	Surface of water	1,000
7.2	Surface of water	1,029
7.4	Cliff Creek, mouth of, surface of water	1,035
7.4	Cliff Creek, 500 feet above, east side river, point on rock	1,045.26
7.5	Surface of water	1,039
7.6	Chechero Creek, mouth of, surface of water	1,049
7.8	Surface of water	1,059
8	Surface of water	1,069
8.2	Surface of water	1,079
8.4	Surface of water	1,089
8.5	Surface of water	1,099
8.6	Surface of water	1,109
9	Surface of water	1,119
9.5	Surface of water	1,129
9.8	Surface of water	1,149
10	East side of river on edge of bank, point on rock	1,152.43
10	Surface of water	1,159
10	Iron bridge, South Carolina side, iron bar under bridge, point on	1,168.95
10	Iron bridge, surface of water	1,166.3
10	High water	1,177
10.5	Surface of water	1,169
10.6	Mouth of creek, surface of water	1,173
10.6	Head of falls, surface of water	1,179
10.8	Mouth of stream, surface of water	1,183
11	Surface of water	1,189
11.4	Surface of water	1,199
11.7	Mouth of stream, surface of water	1,204
12	Surface of water	1,209
12.5	50 feet south of island, east side of river, 10 feet from bank, point on rock	1,217.86
12.7	Surface of water	1,219
12.9	Surface of water	1,223
13	Surface of water	1,229
13.2	Stream, mouth of, surface of water	1,232
13.6	Surface of water	1,239
13.8	South Carolina side of river, at large cliff, point on rock	1,245.53
14	Surface of water	1,249
14	Mouth of Fall Creek, surface of water	1,262

Elevations on Chattooga River from its mouth to Russell Bridge, Ga., 0.7 mile north of Russell, S. C.—Continued.

Distance in miles.		Elevation in feet.
14.5	Surface of water	1,268
14.7	Surface of water	1,279
15	Surface of water	1,289
15.7	Surface of water	1,296
16	Surface of water	1,299
16.6	Rich Creek, mouth, surface of water	1,308
16.8	Surface of water	1,309
16.9	South Carolina side of river, point on rock	1,310.4
17	Surface of water	1,319
17.4	Surface of water	1,329
17.8	Sandy Bottom, 1,000 feet below, east side of river, point on rock	1,332
18	Surface of water	1,340
18.7	Surface of water	1,359
18.7	East side of river, point on rock	1,366.45
18.9	Surface of water	1,360
19.1	300 feet below falls, at bend in river, point on rock	1,376.19
19.2	Foot of falls, surface of water	1,375
19	Head of falls, surface of water	1,381
19.7	Surface of water	1,399
19.8	Rock Creek, mouth of, surface of water	1,406
20	Sandy Ford, surface of water	1,411
20	Sandy Ford, 75 feet north of, 15 feet east of river, nail in root of white oak tree	1,416.55
20.2	Surface of water	1,419
20.6	Surface of water	1,429
20.7	Dick Creek, mouth of, surface of water	1,439
20.8	Surface of water	1,449
21	East side of river, point on rock	1,452.91
21.2	Surface of water	1,459
22	Surface of water	1,469
22.1	Surface of water	1,473
22.3	4 feet east of river, nail in root of large pine tree	1,481.86
22.7	Surface of water	1,479
23	Earl Ford, 100 feet below ford, east side of river, point on rock	1,486.74
23	Surface of water	1,486
23	War Woman Creek, mouth of, surface of water	1,486
23.8	South side of river, point on rock	1,494.13
23.8	Surface of water	1,492
24.8	Surface of water	1,499
25.2	West side of river, point on rock	1,510.51
25.2	Surface of water	1,505

Elevations on Chattooga River from its mouth to Russell Bridge, Ga., 0.7 mile north of Russell, S. C.—Continued.

Distance in miles.		Elevation in feet.
26	Horseback Ford, surface of water	1,518
26.3	Surface of water	1,519
26.4	Ford, 65 feet above, north side of river, nail in live stub (white oak tree)	1,522.66
26.4	Surface of water	1,521
26.8	Surface of water	1,529
27.1	Surface of water	1,539
27.9	Barlow Stream, center of river, point on rock	1,547.26
28	Surface of water	1,549
28.7	Long Bottom Ford, east side, nail in fork of sugar maple tree	1,557.68
29.7	Small stream, mouth of river at, surface of water	1,554
30.6	West Fork, mouth of, surface of water	1,563
30.6	Wooden bridge, above Russell, S. C., southwest side of bridge, point on bolt	1,584.84
30.6	Bridge, surface of water	1,564

BROAD RIVER BELOW CARNESVILLE, GA.

Between June 9 and July 16, 1903, Broad River was surveyed from its mouth, near Lisbon, Ga., to Harrison Bridge, near Carnesville, Ga., a distance of 64½ miles. In that distance there is a fall of 316 feet. The field sheets were plotted on the scale of 1:22,500, and the survey was accompanied with a line of secondary levels based on the primary bench mark of the United States Geological Survey at Lisbon, Ga. During the course of the survey 54 bench marks were established and 109 water elevations determined.

The flow is very gradual from the mouth to Milford Shoals, a distance of 2 miles. These shoals have a fall of 8 feet in a distance of one-third of a mile, and are about 500 feet wide. The river bottoms are wide up to the foot of Anthony Shoals, 5¼ miles from the mouth of the river. Here is the finest power site on the river, there being a fall of 58 feet in 1¾ miles, with rock bottom and rock bluffs on each side. A dam at this point would have to be 1,000 feet long. The rock is granite and would furnish excellent material for building purposes. At the end of these shoals, on the Elbert County side, are the remains of a wing dam which furnished power for a cotton mill now in ruins.

From here to Fishdam Shoals, 9¼ miles, the river has a fall of 9 feet, with wide, cultivated bottoms on either side for most of the distance. At Fishdam there is a 3-foot dam about 250 feet long which furnishes power for a grist and saw mill.

From Fishdam to the mouth of South Broad River, 15½ miles, there is a fall of 23 feet with no shoal of any consequence. The bottoms are wide in most places and are in a high state of cultivation.

One mile above South Broad River are the Detwiler Shoals, with a fall of 7 feet in half a mile. A dam at this point would be about 300 feet long. A mile and a half farther are the lower Moore Shoals, with a fall of 6 feet in a quarter of a mile, and good outcrop of hard rock on both sides. A dam here would be about 350 feet long.

Five miles farther up are the Payton Shoals, with a fall of 4 feet in a quarter of a mile. Here the steep banks show granite on the southeast side.

Two and one-half miles upstream are the Cowpen Shoals, with a fall of 8 feet. This is an excellent site for a dam, having rock bottom and sides. Two miles upstream are Moore Shoals, with a fall of 19 feet in three-fourths of a mile. The river here is about 400 feet wide, with solid rock bluffs on either side.

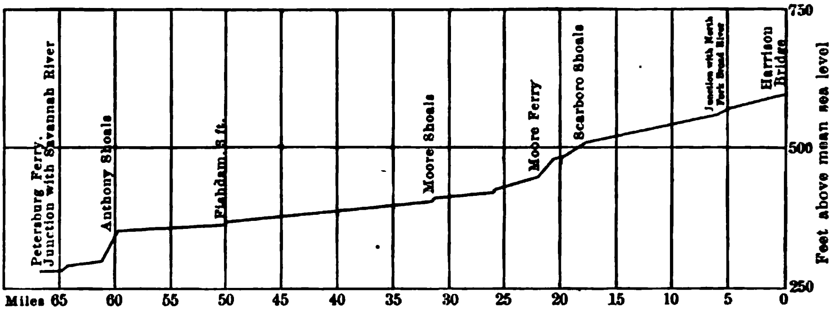


FIG. 5.—Profile of Broad River below Carnesville, Ga.

One-half mile beyond are Brown Shoals, with a 10-foot fall in one-third of a mile. A dam here would be about 400 feet long and would have an excellent foundation. One and three-fourths miles upstream are the Bryant Shoals, with a fall of 20 feet in 1¼ miles. This is an excellent site for a dam, having good bottoms and rock sides.

For 12 miles upstream to Double Bridge the shoals are small and do not seem important. From Double Bridge to Harrison Bridge, at which point the survey ended, a distance of 6 miles, the river is very narrow and shoaly, but the volume of water is small.

The elevations in the following list are based on a bronze tablet in a brick wall of R. L. Cade's store at Lisbon, Ga., marked "Atlanta 328," the elevation of which is accepted as 327.850 feet above mean sea level. They accord with the 1903 adjustment of the precise-level net.

The leveling was done under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville.

Distance in miles.		Elevation in feet.
0.0	Lisbon, mouth of Broad River, 870 feet northwest of, south side of ferry road, nail in twin water oak	295.77
.0	Broad River, mouth of, surface of water	280
.0	Broad River, 870 feet northwest of mouth, high-water bench mark	300
.6	Small stream, near, surface of water	281
1.4	Mill Ford Shoals, foot of, surface of waters	281
2.1	Mill Ford Shoals, middle of, surface of water	288
2.4	Mill Ford Shoals, head of, surface of water	289
2.4	Mill Ford Shoals, 200 feet east of river, near 5-inch elm tree, nail in live stob	304.9
2.7	Center of bend, surface of water	291
3.4	Dubose Ferry, 300 feet above, surface of water	292
4.7	Anthony Shoals, foot of, surface of water	293
5	Anthony Shoals, surface of water	295
5.2	Anthony Shoals, at large bend in river, surface of water	307
5.2	Anthony Shoals, at rock cliff, surface of water	310
5.2	Anthony Shoals, at rock cliff, point on rock, 1 foot west of river	311.57
5.4	Anthony Shoals, surface of water	319
5.6	Anthony Shoals, surface of water	329
5.8	Anthony Shoals, in front of old factory, surface of water	339
6	Anthony Shoals, at old dam, east edge of river, nail in root of birch tree	347.77
6	Anthony Shoals, surface of water	351
6.4	Anthony Shoals, head of, surface of water	355
6.5	Burton Ferry, 6 feet south of river, nail in root of Spanish oak tree	361.44
6.5	Surface of water	355
6.5	Burton Ferry, high water	364
7.1	Surface of water	355
8.7	Mouth of creek, surface of water	356
8.7	60 feet south of river, 25 feet east of creek, nail in sweet gum tree	367.59
10	Surface of water	356
10.9	Bakers Ferry, small shoals, surface of water	356
11	Bakers Ferry, 20 feet southwest of river, nail in root of large birch tree	364
11	Bakers Ferry, surface of water	357
11.8	Wahache Creek, mouth of, surface of water	360
13.8	Bells Bridge, north side, nail in joist	373.69
13.8	Bells Bridge, surface of water	360
13.8	Bells Bridge, high water	386
13.8	Bells Bridge, floor of	393.2
15	Bells Bridge, 250 feet north of river, large pine tree near path to river, nail in tree	375.34
15.4	Mouth of small stream, surface of water	361
15.6	Falling Creek, mouth of, surface of water	362

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville—Continued.

Distance in miles.		Elevation in feet.
16	Foot of shoals, surface of water	363
16.4	Fishdam, foot of, surface of water	365
16.4	Fishdam, head of, surface of water	368
16.4	Fishdam Ferry, north side river, nail in root of large water oak tree	374.35
16.4	Fishdam Ferry, surface of water	368
16.4	Fishdam Ferry, south side of, nail in root of gum tree	374.87
17.7	Surface of water	368
18.9	North of river, point on rock	386.66
18.9	Surface of water	370
20	Grimes old ferry, edge of river, nail in root of white oak tree	375.51
20	Grimes old ferry, surface of water	371
21.3	500 feet south of river, river road, 25 feet south of, nail in root of Spanish oak	388.89
22.1	Mouth of large creek, surface of water	372.8
22.5	Pinegrove, 400 feet north of river, 900 feet west of large creek, nail in root of pine tree	398.51
23.1	Mattox Bridge, north side, nail in plank	401.35
23.1	Mattox Bridge, surface of water	374
23.1	Bridge floor	404
23.1	High water	400
24.8	Rock cliff, near, 40 feet south of river, nail in root of gum tree	397.88
24.8	Surface of water	377
25.2	Jones Ferry, east side, nail in root of water oak tree	393.43
25.2	Jones Ferry, surface of water	377
25.2	High-water mark	401
25.5	Jones Ferry, 0.3 mile above, 40 feet west of river, nail in white oak tree	394.38
26	Surface of water	380
26.7	Millstone Creek, mouth of, 60 feet east of, 25 feet south of river, nail in side of box elder	392.64
26.7	Millstone Creek, mouth of, surface of water	381
28	Gold Mine Cliff, surface of water	384
28.5	Horseshoe Bend, head of, 150 feet south of river, in cornfield, nail in Spanish oak	405.67
28.5	Dove Creek, mouth of, surface of water	386
28.6	Bend in river, surface of water	396.4
28.6	Surface of water	386
30	260 feet north of river, nail in root of pine tree	411.3
30.9	Surface of water	391
31	Martins old ferry, near spring, point on rock	420.14
31.3	Junction South Fork and Broad River, southeast point of rivers, nail in side of birch tree	395.86
31.3	Surface of water	391

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville—Continued.

Distance in miles.		Elevation in feet.
32.4	Detwiler Ferry, foot of shoals, surface of water	395
32.9	Detwiler Ferry, east side, edge of water, slanting Spanish oak, nail in	406.07
32.9	Detwiler Ferry, head of shoals, surface of water	402.1
32.9	Detwiler Ferry, high water	423.6
33.4	Seaboard Air Line bridge, abutment, east side of river, 350 feet from	420.28
33.4	Seaboard Air Line bridge, surface of water	402
34	Moore Shoals, surface of water	404
34.4	Old mill, 25 feet east of river, point on rock	416.23
34.4	Old mill, mouth of stream, surface of water	409
34.4	Moore Shoals, head of, surface of water	411
34.7	Bells Ferry, edge of river, 2 feet from road, overhanging Spanish oak, nail in	418.87
34.7	Bells Ferry, surface of water	412.3
34.7	Bells Ferry, high water	430
35.9	Harpers Ferry, north side of river, east side ferry, nail in root of black gum tree	422.54
35.9	Harpers Ferry, surface of water	414
35.9	Harpers Ferry, high water	432
36.8	Holly Branch, mouth of, surface of water	416
37.5	Moon Ferry, east of ferry, nail in side of white oak tree	423.19
37.5	Moon Ferry, surface of water	418
37.8	Surface of water	419
37.9	Mouth of creek, surface of water	420
38.6	Payton Shoals, foot of, surface of water	422
39	Payton Shoals, east side of river, nail in sycamore tree	428.57
39	Payton Shoals, head of shoals, surface of water	425
39.1	South Payton Ferry, 25 feet from river, east side of ferry, nail in side of dead willow tree	431.35
39.1	Payton Ferry, high water	449
39.1	Payton Ferry, surface of water	427
39.1	Payton Ferry, high water	449
39.4	Payton No. 2, head of shoals, surface of water	429
39.8	Victory Ferry, overhanging birch tree. nail in side of	432.17
39.8	Victory Ferry, surface of water	430
39.8	High water	450
40.4	Moon Ferry, nail in root of white oak tree	442.62
40.4	Moon Ferry, foot of shoals, surface of water	431
40.5	Moons Shoals, head of, surface of water	433
41.1	Bend in river, 1,500 feet east of Mill Creek, east side river, point on rock	443.14
41.1	Surface of water	438

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville—Continued.

Distance in miles.		Elevation in feet.
41.4	Mill Shoal Creek, mouth of, surface of water	439
41.4	Surface of water	441
42.2	Head of shoals, surface of water	450
42.7	Moore Ferry, west side of, large spruce oak tree, nail	455.77
42.7	Moore Ferry, surface of water	450
42.7	High water	460
43.0	Moore Shoal, at spring, foot of shoals, surface of water	454
43.3	Shoals, surface of water	462
43.3	Moore Shoals, near head of, point on rock	470
43.8	Browns Ferry, burnt stump northeast of river, nail in	482.09
43.8	Browns Ferry, near head of Moors shoals, surface of water	471
44.2	Moore Shoals, head of, surface of water	482
44.6	Dudleys Shoals, east bank of river, point on rock	489.28
44.6	Surface of water	482
45.5	Dudley Ferry, black gum tree north side of ferry, nail in root	502
45.5	Dudley Ferry, surface of water	487
45.5	High-water mark	504
45.6	Bryant Shoals, foot of, surface of water	489
46.2	Bryant Shoals, head of, surface of water	496
46.5	Sawmill, Spanish oak tree, 50 feet from river, nail in root of	506.65
46.5	Surface of water	502
46.5	Head of shoals, surface of water	506
47.7	Bluestone Creek, north side river, 1.2 miles below Bluestone Creek, point on rock	518.38
47.7	Surface of water	512
48.9	Mouth of Bluestone Creek, surface of water	617
49.6	Surface of water	521
50.4	New Lattice Bridge, east side of river, nail in floor of	546.44
50.4	Bridge floor	548.8
50.4	Bridge, surface of water	523
50.4	High-water mark	548.1
51.2	Mouth of stream, foot of shoals, surface of water	523.7
51.6	Head of shoals, surface of water	526
52.3	Winters Creek, just below bend in river, surface of water, temporary bench mark	545
52.4	Winters Creek, mouth of, head of shoals, surface of water	529
53.2	Surface of water	532
53.9	Mouth of stream, surface of water	535
54.7	Bragg Ferry, 2 feet from river, nail in root large red oak tree	541.75
54.7	Bragg Ferry, mouth of Hudson River, surface of water	537
54.7	High-water mark	567

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville—Continued.

Distance in miles.		Elevation in feet.
55.2	Surface of water	541
55.7	Dove Bridge, southeast corner of, nail in side of white oak tree	561.78
55.7	Dove Bridge, surface of water	542
55.7	High water	569
57.2	Foot of shoals, surface of water	548
57.3	Head of shoals, surface of water	552
57.6	Surface of water	554
57.7	Creek, 60 feet southeast of mouth of, nail in white oak	563.30
57.7	Creek, mouth of, surface of water	556
58.1	Mouth of stream, surface of water	556
58.8	Middle Broad and Broad rivers, forks of, walnut tree 75 feet west of fork, nail in side	575.16
58.8	Surface of water	557
59.1	Double Bridge, northwest side of, nail in plank	581.11
59.1	Surface of water	563
59.1	High-water mark	576
59.1	Bridge floor	584
59.7	Head of shoals, surface of water	570
59.9	Surface of water	573
60.6	Corey Creek, 0.6 mile below, large rock projecting out from bank point on	581.02
60.9	Small shoals in river, surface of water	580
60.9	Corey Creek, mouth of, surface of water	581
61.5	Bend, on east side river, point on rock	591.15
61.5	Surface of water	584
62.1	Fish dam, surface of water	586
62.2	Surface of water	588
62.3	Bend in river, east side, point on rock cliff	598.59
62.8	Philip Shoals, head of, surface of water	591
63.2	Stephens Creek, mouth of, surface of water	592
63.4	Ford, oak tree 75 feet north of, nail in north side of	603.49
63.4	Surface of water	593
63.4	Surface of water	594
64.6	Harrison Bridge, east of, north of river, nail in root of Spanish oak tree	607.07
64.6	Surface of water	596
64.6	Bridge floor	613.7
64.6	High-water mark	612

SOUTH AND OCMULGEE RIVERS, FROM CONSTITUTION TO MACON, GA.

South and Ocmulgee rivers were surveyed from Constitution to Macon, Ga. For the first 28 miles the topography was plotted on the scale of 1:45,000, but subsequently on the standard scale of 1:22,500. The levels are secondary levels based on the United States Geological Survey permanent bench mark at Constitution, Ga. Eighty-six bench marks were established and 200 water-surface elevations were recorded.

South River rises in the city of Atlanta and flows in a southeasterly direction for 56½ miles and then joins Yellow River to form the Ocmulgee. For 11 or 12 miles below Constitution, the beginning of the survey, the river is narrow, being about 15 feet wide at places. All along the north side of the river in this stretch are extensive beds of clay, which at certain points are being used for brickmaking.

Flakes' mill, 11 miles from Constitution, is the first power now utilized on the river. At this point the dam is 6 feet high. Below for 6 miles the river remains shoaly and narrow until Flat Shoal is reached, where there is a fall of 12 feet with a small gristmill using a little of the power. Near here the river is very crooked and incloses in its large loops flat, sandy stretches of country, which are very fertile. Near Flat Shoal is Littlestone Mountain, with valuable granite quarries.

At Albert Shoals, 7 miles farther down, there is a fall of 16 feet in half a mile. The river is here about 125 feet wide and the volume is much increased by a number of tributary streams. The banks are sloping, with no rock visible. The power site has recently been purchased by a company which proposes to develop it.

At Simm's mill, 3 miles below, is a small 2-foot dam. From here to Peachstone Shoals, a distance of 11 miles, there is a fall of 32 feet, the river winding through good bottom lands. Camp and Honey creeks enter the river in this stretch and add a large amount of water. At Peachstone Shoals is a 2-foot dam which backs the water for one-half mile, and with a canal about 400 feet long develops a head of about 9 feet, the power from which drives several turbines operating a grist and a saw mill. Soft rock is visible on the west bank, while the east bank is a flat sand bar.

About 8 miles below are the Snapping Shoals, where there is a fall of 20 feet in a distance of 300 yards. Near the lower end of the rapids several small islands divide the channel into several parts. Solid rock is close to the surface on both sides of the river. A portion of the power at this point is used in operating a large roller flour mill and sawmill. Mr. DeLoach, the owner, is taking steps to develop all the power and intends erecting a large cotton factory at this point.

Three miles below here is Island Shoal, with a fall of 10 feet in 250 yards. Here there is a flour mill and a furniture factory, both operated by a 3-foot dam with a canal 1,200 feet long. The head could be increased by adding 5 feet more to this dam without materially damaging any property above. This site is an excellent location for power development, as the banks are high and solid and the length of the dam would probably not exceed 250 feet.

Eight miles farther down is the Barnes Shoal, at the mouth of Yellow River. A dam here would be about 700 feet long. There are excellent foundations and about a 9-foot fall.

Farther down the stream are Keys Shoals, with a 3-foot fall and several minor riffles to Lloyds Shoals, which has a fall of 43 feet in about 2½ miles, at the lower end of which there is a good dam site. The river at this point is only about 350 feet wide, with solid rocky banks rising 50 feet on either side. A 45-foot dam at this point would do a trifling amount of damage to property above.

Ten miles downstream is Smith Shoal, with a fall of 12 feet, where a 2-foot dam and a long canal at present run Smith's gristmill. At Lamars Shoals, 2 miles below, there is a fall of 19 feet in 1 mile with a 5-foot dam and a canal running a flour mill. The river is here about 1,000 feet wide, with high, rocky banks, and has a number of small islands and large rocks scattered all through it. Twelve miles farther down, at Juliette, Ga., is an important shoal which has been developed by Doctor Glover. There is a 15-foot fall in one-half mile, which has been developed by an 8-foot dam with a short canal,

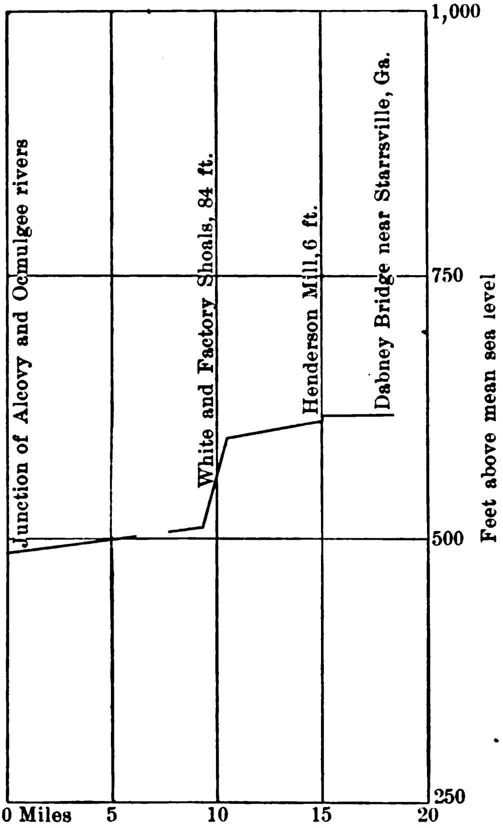


FIG. 6.—Profile of South and Ocmulgee rivers from Constitution to Macon, Ga.

and runs the Glover cotton mills and the Juliette Milling Company's plant.

Twelve miles below are Dames Shoals, with an 8-foot fall in 600 feet. A 6-foot dam at this point supplies Carstarphens gristmill, which is a large wholesale plant. The bed of the river here is solid rock, but a higher dam would flood valuable bottom lands above.

Popes Shoals have a 5-foot fall in a quarter of a mile, and Taylor's shoals have a 5-foot fall within a few hundred yards.

The elevations in the following lists are based upon an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta marked "1050 M C," the elevation of which is accepted as 1,049.546 feet above mean sea level. The leveling on South and Ocmulgee rivers is adjusted to accord with elevations of precise level bench marks at Constitution, Holton, and Macon, Ga., by the 1903 adjustment.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, level man.

Elevations on South River from Constitution to junction with Yellow River (head of Ocmulgee River) near Worthville.

Distance in miles.		Elevation in feet.
0.0	Constitution, 25 feet south of Southern Railroad, 4 feet east of signboard, iron post marked "847 Morehead 1898"	847.006
.0	Surface of water	772
2	Intrenchment Creek, mouth of, nail in root of black gum	773.77
2	Surface of water	770
2.8	McNeals Bridge, nail in root of sycamore tree	769.57
2.8	Surface of water	768
7	Kellers Bridge, north end, iron bolt	751.92
7	Surface of water	750
10	Shoal Creek bridge, surface of water	737
12.6	Flake's mill, nail in root of birch tree	733.26
12.6	Surface of water	728
16.3	Flat Shoal Bridge, south side of river, east side of approach, on stone abutment	708.71
16.3	Surface of water	698
	Foot of shoal	686
20.6	Parkers Bridge, nail in root of sweet-gum tree	678.76
20.6	Surface of water	672
23.6	Daniels Bridge, lower side, right end of, point of stone pier	667.97
23.6	Surface of water	649
25.3	Simms Bridge, surface of water	635
26.4	Knight Creek, 50 feet above mouth, on root of sycamore, nail	639.28
26.4	Surface of water	629

Elevations on South River from Constitution to junction with Yellow River (head of Ocmulgee River) near Worthville—Continued.

Distance in miles.		Elevation in feet.
31	Oglesbys Bridge, 25 feet above, nail in root of oak tree	622.02
31	Surface of water	614
36	Peachstone Falls, nail in root of water oak	605.71
36	Peachstone Shoals, head of, surface of water	597
	Peachstone Shoals, foot of, surface of water	589
41	Butler Bridge, 30 feet below, nail in root of red-oak tree	587.15
41	Surface of water	569
43	Snapping Shoals, head of, surface of water	562
43.1	Snapping Shoals Bridge, 40 feet from north approach, on root of water oak	559.66
	Snapping Shoals, foot of, surface of water	542
	Island Shoals, head of, surface of water	536
45.3	Island Shoals Bridge, near south approach of, nail in root of white oak	534.89
45.3	Surface of water	525
50.8	Manns Bridge, on south side of river, 20 feet below, nail in root of hickory tree	518.49
50.8	Surface of water	503
52.1	Yellow River, mouth of, opposite, nail in root of pine tree	506.94
52.1	Surface of water	498

Elevations on Ocmulgee River from head, at junction of South and Yellow rivers, near Worthville, to Macon.

Distance in miles.		Elevation in feet.
0.0	Yellow River, opposite mouth of, nail in root of pine	506.94
.0	Surface of water	498
	Alcovy River, opposite mouth of, nail in root of large white oak	494.27
	Surface of water	484
4.1	Tusahaw Creek, mouth of, head of Lloyds Shoals, nail in root of water oak	482.12
4.1	Surface of water	472
6.4	Lloyds Shoals, foot of, surface of water	429
7.4	Pittmans Ferry, near south side of, nail in root of beech tree	434.96
7.4	Surface of water	425
7.9	Yellow Water Creek, 30 feet above mouth of, nail in root of hickory tree	433.97
7.9	Surface of water	422
9.2	Giles Ferry, nail in root of pine tree	430.01
9.2	Surface of water	420

Elevations on Ocmulgee River from head, at junction of South and Yellow rivers, near Worthville, to Macon—Continued.

Distance in miles.		Elevation in feet.
9.2	Smiths Shoals, head of, surface of water	420
10.7	Smiths Shoals, foot of, surface of water	408
10.9	Smiths Ferry, on south side, 20 feet above landing, nail in root of ash tree	410.44
10.9	Surface of water	407
11.9	Lemars Shoals, head of, surface of water	406
11.9	Lemars Shoals, foot of, surface of water	387
14.1	Goodmans Ferry, south side of river, nail in root of large red oak tree	400.74
14.1	Surface of water	382
17.8	Wards Ferry, south side of river, nail in root of water oak	392.69
17.8	Surface of water	375
19.4	Big Sandy Creek, Southern Railway bridge over, 4 feet south of rail, 2 feet from east end bridge, point on stone pier	399.45
19.4	Surface of water	374
22.5	Bridges Ferry, south side of river, nail in root of large water oak tree	382.82
22.5	Surface of water	370
22.9	South bank river, 10 feet from water, nail in root of large oak tree	388.15
22.9	Surface of water	368
24.4	Towaliga River, south bank at mouth of, nail in root of red oak	379.34
24.4	Surface of water	368
25.4	Glovers Shoals, head of, surface of water	366
25.9	Glovers Shoals, foot of, surface of water	351
27.3	Glovers Ferry, 10 feet south of west approach, nail in root of beech tree	361.10
27.3	Surface of water	346
28.5	Mitchells Ferry, 10 feet south of west end, nail in root of red oak tree	361.74
28.5	Surface of water	344
32.4	25 feet from river, opposite milepost, nail in root of thunderwood tree	340.79
32.4	Surface of water	330
33.9	Danns Ferry, 10 feet south of west end of, nail in root of ash tree	335.63
33.9	Surface of water	328
34.9	Carstarphens Shoals and dam, head of, surface of water	328
	Foot of dam, surface of water	322
35	Foot of shoals, surface of water	320
36.4	Rum Creek, north abutment west end of Southern Railway bridge over	347.32
36.4	Surface of water	318
36.9	Popes Station, in front of, top of west rail	348.23
36.9	Popes Ferry, south end of, nail in root of water oak	326.88
36.9	Surface of water	318
37.9	Head of shoals, surface of water	317
37.9	Foot of shoals, surface of water	312

Elevations on Ocmulgee River from head, at junction of South and Yellow rivers, near Worthville, to Macon—Continued.

Distance in miles.		Elevation in feet.
41.9	Holton, 35 feet north of station; 29 feet west of center of track, iron post marked "339 Morehead 1898"	338.733
41.9	Surface of water	299
47.7	Virgin, west rail of upper switch of Southern Railway at	322.52
47.7	Surface of water	282
49.9	Macon waterworks, just below, 30 feet east of track, 100 feet below mouth of small creek on south side of river, nail in root of pine tree	301.88
49.9	Surface of water	278
51.9	Macon, post-office building, at corner of Mulberry and Third streets, at left of Mulberry street entrance, in water table, aluminum tablet marked "334 Morehead 1898"	333.942

YELLOW RIVER BELOW YELLOW RIVER, GA.

Yellow River was surveyed from its mouth, near Worthville, Ga., upstream to Simmons's mill, near Yellow River, Ga., a distance of 57 miles. The scale upon which the field work is plotted is 1:22,500. During the course of the survey 54 bench marks were established and 103 water-surface elevations obtained.

Yellow River flows in a southeasterly direction and contains some valuable power sites, both developed and in a natural condition. One-half mile above its mouth are the Indian Fishery Shoals, where there is a fall of 12 feet in about 200 feet. The river is here about 300 feet wide, but a narrow neck projecting just below the shoals and several rocky islands considerably reduce the probable expense of construction. There is a gristmill and a cotton gin in operation here, using perhaps nine-tenths of the available power.

For 18 miles above the river runs between high banks, alternating with low bottoms to Langdon Shoals, without any marked shoals except at Lees, where there is a fall of 2½ feet, and Flat Shoals, with a 1-foot fall. Langdon Shoals have only a 4-foot fall.

Three miles above, at Porterdale, is the finest power site on the river, where extensive developments have been made by the Bibb Manufacturing Company, which has a large cotton and twine factory at this point. Here there is a fall of 67 feet in half a mile, with a 12-foot dam at the upper end of the shoal. The banks at the foot are very high, but gradually become lower until just above the dam large bottoms begin and continue for 5 miles. Five miles above the Georgia Railroad is the next power, McDaniels Shoals, where there is a 7-foot fall in a very short distance, and a 6-foot dam operating a gristmill. The north bank is solid rock, sloping gently, but the south bank shows no outcrop. The power developed by this dam could be much increased with small cost.

Above this point the bottoms become narrower and the river banks more rugged and higher until at Milstead, Ga., 4½ miles above, there is a fall of 45 feet in half a mile. A 15-foot dam, with canal, is completed here, and two large cotton factories are being constructed. Railroad facilities have recently made this a valuable site for mills, and a large granite quarry has been opened up at the same point.

Eleven miles above are Anniestown Shoals, with a 23-foot fall, where there is an 11-foot dam, which formerly supplied power used to operate a cotton mill of the old type. The banks here are all hard, unseamed rock, and the site could be developed into valuable property.

Two and one-half miles above are some shoals with a 14-foot fall in half a mile. The power is undeveloped, but is in a rather inaccessible section of the country. Above this point the river flows through a very rough country for 10 miles, passing no important shoals until the next power is reached, at Yellow River, Ga., the end of the survey. Here is a dam 7.3 feet high, which operates the Simmons roller mills. The lower reaches of the river are thickly settled, cotton and grain being the principal crops, but the upper part of the river is almost entirely in timber land.

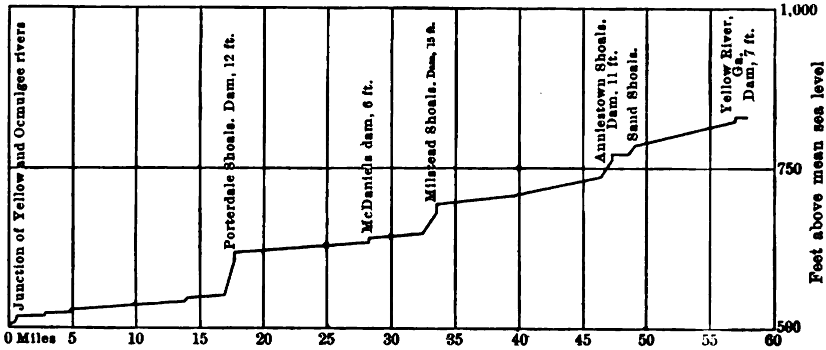


FIG. 7.—Profile of Yellow River below Yellow River, Ga.

The elevations in the following list are based on an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta, marked "1,050 M C," the elevation of which is accepted as 1,049.546 feet above mean sea level. The initial point of this list is a bench mark of flying levels on Ocmulgee River.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Yellow River from mouth near Worthville to Yellow River, Ga.

Distance in miles.		Elevation in feet.
0.0	Yellow River, mouth of, opposite, nail in root of pine tree	506.94
.0	Surface of water	500
.5	Indian Fishery Shoals, 10 feet of from water, nail in root of ash tree	517.24
.5	Foot of shoals, surface of water	504
.0	Head of Indian Fishery Shoals, surface of water	516
2.5	Allens bridge, east bank, 20 feet from river, nail in root of maple tree	528.49
2.5	Surface of water	517
4.7	Lees Shoals, foot of, west bank, nail in root of ash tree	528.49
4.7	Surface of water	520
	Lees Shoals, head of, surface of water	523
6.2	Pickett Bridge, on east bank, nail in root of white oak	539.23
6.2	Surface of water	526
10.7	Flat Shoal Bridge, west bank, nail in root of white oak	551.24
10.7	Surface of water	534
13.8	Langdons Shoals, west bank, 15 feet from river, nail in root of white oak	549.69
13.8	Surface of water	539
	Langdons Shoals, head of, surface of water	543
16.9	Porterdale Shoals, foot of, 10 feet from river, west bank, nail in root of white oak	561.05
16.9	Surface of water	549
	Porterdale dam, foot of, surface of water	604
	Porterdale dam, head of, surface of water	616
17.7	Porterdale, 30 feet from dam, 20 feet from south approach, nail in root of white oak	618.38
17.7	Surface of water	616
17.7	Wagon bridge, east side of river, at extreme south end of bridge, top of steel post of railing	627.81
20.8	Browns Bridge, 60 feet above, 10 feet from river, on root of gum tree	622.81
20.8	Surface of water	611.6
22.8	Tin Bridge, on west bank river, nail in root of poplar tree	627.49
22.8	Surface of water	617
23	Georgia Railroad bridge, west side of river, on top of rock, chisel mark	642.05
23	Surface of water	617
24.3	Hendricks Bridge, north bank of river, nail in root of water oak	639.11
26	Haynes Creek, opposite mouth of, nail in root of water oak	632.26
26	Surface of water	624.6
28.2	McDaniels Bridge, west bank of river, nail in root of large water oak	644.17
28.2	Surface of water	632
	McDaniels dam, head of, surface of water	641
30.5	West side of river, Pine Log Bridge, 10 feet below, nail in root of pine	650.55
30.5	Surface of water	641

Elevations on Yellow River from mouth near Worthville to Yellow River, Ga.—Continued.

Distance in miles.		Elevation in feet.
32.2	Botosh Creek, 100 yards above mouth of, left bank of river, nail in root of pine	653.96
32.2	Surface of water	644
32.8	Foot of Milstead Shoals, west bank, nail in pine tree	657.41
32.8	Surface of water	647
33	Milstead, foot of dam, surface of water	677
33	Milstead, top of dam, surface of water	692
33	40 feet above wagon bridge, on south side of river, nail in root of large white oak	701.33
33	Surface of water	692
35.4	Irvins Bridge, 20 feet above, left bank of river, nail in root of hickory tree	697.83
35.4	Surface of water	692
36.5	Right bank, nail in root of water oak	700.62
36.5	Surface of water	694
39.4	Johnsons Bridge, east end of, top of bolt	717.53
39.4	Surface of water	702
40.2	Surface of water	705
40.3	Surface of water	707
40.8	Surface of water	709
40.9	Surface of water	711
40.9	Old dam, west side, on point in stone masonry	722.88
40.9	Surface of water	712
41.3	Foot of shoals, surface of water	714
	Head of shoals, surface of water	715
41.9	Opposite shoals, right bank, 20 feet from stream, nail in root of white oak	730.91
41.9	Surface of water	715
42.4	Mountain Creek, opposite, nail in root of white oak	727.91
42.4	Surface of water	720
43.2	Rock Bridge, on left bank, top of stone pier of	740.60
43.2	Surface of water	724
44	West bank, 10 feet from river, nail in root of ash tree	728.48
44	Surface of water	727
45.5	Opposite foot of shoals, nail in root of hickory tree	748.83
45.5	Surface of water	729
	Anniestown Shoals, foot of, surface of water	737
	Anniestown dam, foot of, surface of water	760
	Head of dam, surface of water	771
47.2	Anniestown, east bank of Haydens Branch, nail in root of large birch tree	777.64
48.6	Old mill, on large rock opposite, chisel mark	788.55

Elevations on Yellow River from mouth near Worthville to Yellow River, Ga.— Continued.

Distance in miles.		Elevation in feet.
48.6	Surface of water	772
	Head of shoals, surface of water	786
50.5	Sextons Bridge, on stone pier at, top of iron bolt	809.94
50.5	Surface of water	791
51.7	Opposite shoals, nail in root of pine	808.42
51.7	Surface of water	793
	Foot of shoals, surface of water	797
	Head of shoals, surface of water	802
53	Head of shoals, nail in root of hickory tree	818.17
53	Surface of water	804
54	Surface of water	807
55	Yellow River Bridge, left bank, nail in root of oak	825.41
55	Surface of water	815
55.7	Yellow River, east bank, 100 yardsa bove Simmons's mill, nail in root of large water oak	834.86
	Simmons's mill, below dam, surface of water	819
	Simmons's mill, head of dam, surface of water	826

ALCOVY RIVER BELOW DABNEY'S BRIDGE, GEORGIA.

In connection with this survey 17 bench marks were established and 26 water elevations were recorded. The total fall in the distance surveyed is 231 feet, but at only two points, namely, White and Factory shoals and Henderson Shoals, is the fall considerable. The remainder of the river is mostly sluggish, and tree trunks, driftwood, and other débris greatly retard the flow, so that during the rainy season the river is slow to discharge, causing the water to rise higher or spread out wider than is usually the case with rivers in this section of Georgia. The average width of the river is about 125 feet, except where shoals occur, at which points it sometimes widens to 300 feet. Very wide and low bottom lands are on each side for the first 7 miles upstream from its mouth. Then the topography suddenly changes and is much more abrupt and broken for several miles.

At the mouth of Bear Creek, which enters from the east 8 miles above the mouth of the Alcovy, is the beginning of White and Factory shoals, which form one continuous series with a fall of 83 feet in one-half mile. Here the river is in a gorge 300 feet wide, with banks over 100 feet high at several places, and midway of this shoal is an excellent site for a dam. Granite, apparently free from seams, is exposed at the surface on both sides of the river, while the river bed itself is solid rock. A dam at this point would be approximately 250 feet long. At the upper end of the shoals is another good site with the same character of bottom. A dam would have to be about 325 feet in length, and a large volume of water could be stored through the dry season, as the valley widens just above the dam site. A dam at either site would require a canal from the dam to the foot of the shoals. An old corn mill at this point uses a small wooden dam to divert the water into its flumes. Many years ago a large cotton factory stood on this site, but it was burned and never rebuilt.

Six miles above these shoals are Henderson Shoals, with a fall of 2 feet. A 6-foot dam has been erected here to supply power for a large gristmill, the back water from which extends to Dabney's bridge, 4 miles above.

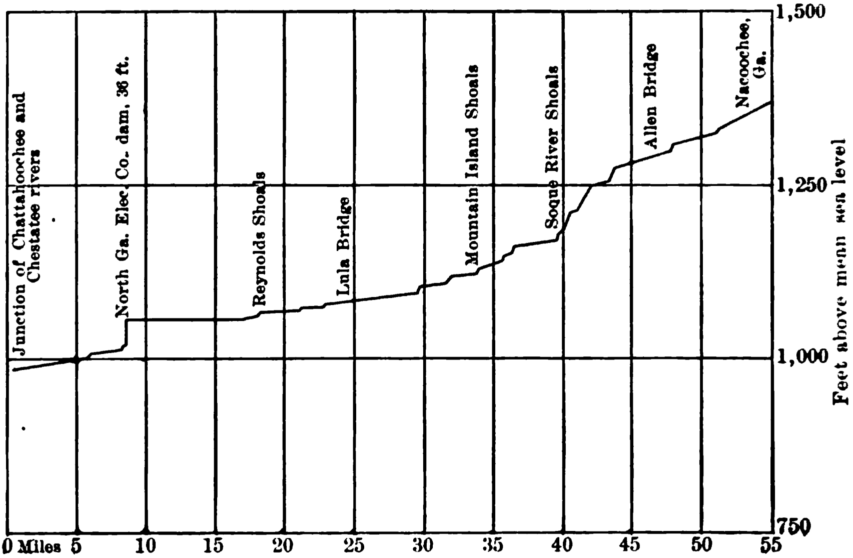


FIG. 8.—Profile of Alcovy River below Dabney's bridge, Georgia.

The construction of dams at any other points than those described would result in the sacrifice of much valuable bottom land.

The soil is very fertile, and splendid crops of cotton on the high lands and corn in the bottoms are grown on both sides of the river. With better drainage, however, a much larger amount of land could be reclaimed and made valuable for cultivation.

The elevations in the following list are based upon an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta marked "1050 M C," the elevation of which is accepted as 1,049.546 feet above mean sea level, as determined by the 1903 adjustment. The initial point of this list is a bench mark of flying levels on Ocmulgee River.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Alcovy River, from mouth, near Worthville, to Dabney's bridge, near Starrsville.

Distance in miles.		Elevation in feet.
0.0	Alcovy River, mouth of, opposite, on west bank of Ocmulgee River, nail in root of white oak	494.27
.0	Surface of water	484
1	Right bank of river, nail in root of ash tree	493.73
1	Surface of water	487
2	East bank of river, near water, nail in root of ash tree	498.40
2	Surface of water	492
3.9	Waters's bridge, spike in northeast corner	506.55
3.9	Surface of water	493
4.9	West side of river, near water, nail in root of ash tree	505.37
4.9	Surface of water	497
5.9	Left bank of river, nail in root of birch tree	505.51
5.9	Surface of water	500
6.3	Mackey Shoals, opposite foot of, on left bank, nail in root of ash tree	512.77
6.3	Mackey Shoals, foot of, surface of water	502
6.4	Mackey Shoals, head of, surface of water	504
8.2	Mackey Second Shoals, opposite foot of, left bank, nail in root of birch tree	518.50
8.2	Mackey Second Shoals, foot of, surface of water	505
	Mackey Second Shoals, head of, surface of water	508
9	Newton Factory Shoals, foot of, surface of water	509
9.2	Dam at White's mill, on Newton Factory Shoals, opposite, nail in root of black gum	562.86
9.2	Dam, foot of, surface of water	553
9.2	Dam, top of, surface of water	558
9.8	Newton Factory Bridge, on lower end of, on nut, top of bolt	592.81
9.8	Surface of water	582
10	Newton Factory Shoals, head of, surface of water	592
10.8	Left bank of river, nail in root of red-oak tree	619.86
10.8	Surface of water	593
11.5	Foot of shoals, surface of water	594
11.55	Head of shoals, surface of water	596
12.3	Left bank of river, nail in root of water oak	604.59
12.3	Surface of water	597
13	West bank, opposite shoals, nail in root of large beech tree	604.88
13	Surface of water	598
13.3	East bank river, nail in sweet-gum tree	612.85
14	Left bank river, nail in root of water oak	620.76
14	Surface of water	602
15	Henderson's bridge and mill, right bank of river, near end of bridge, nail in root of post oak	618.99
15	Surface of water	604

Elevations on Alcovy River, from mouth, near Worthville, to Dabney's bridge, near Starrsville—Continued.

Distance in miles.		Elevation in feet.
15	Henderson's mill, foot of dam, surface of water	607
15	Henderson's mill, head of dam, surface of water	613
18.3	Dabney's bridge, west side of river, near end of, nail in root of water oak (raised cut with hatchet)	627.22
18.3	Surface of water	615

TOWALIGA RIVER BELOW HIGHFALLS, GA.

Towaliga River was surveyed from its mouth, near Berner, Ga., to Highfalls, Ga., a distance of 21.7 miles. The levels are based on a line carried down South and Ocmulgee rivers from Constitution earlier in the season. The plane-table sheets were all plotted on the scale of 1:22,500. Twelve bench marks were established and 23 water-surface elevations were determined.

Towaliga River flows in a southeasterly direction and empties into Ocmulgee River. In the distance surveyed there is a fall of 194 feet, but with the exception of Highfalls there are few shoals or rapids. For 21 miles above its mouth the stream does not average more than 50 feet in width, and is very shallow. It is swift and has a clean bed.

At Highfalls there is a drop of 95 feet in a distance of 3,000 feet, in the middle of which there is a sudden drop of 42 feet, known as the Highfalls. This is an excellent dam site, for, although during the normal stage of water the volume is small, there are splendid facilities to store the water above, as the bottom is widened out into a natural basin. A flour mill has been in operation here for over one hundred years, but it uses only a trifling part of the power. It is now proposed to erect a 25-foot dam at this point to supply electric power for a railway to Indian Springs, Ga., a summer resort 8 miles from Highfalls, and also for lighting the town of Forsythe, 14 miles to the southwest. Property for 6 miles above the falls has been purchased for a storage basin. Between Highfalls and the mouth of the river there are good bottom lands, but the country is thinly settled and most of it is still in timber. The principal crops are cotton and corn.

The elevations in the following list are based upon an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta, marked "1050 M C," the elevation of which is accepted as 1,049.546 feet above mean sea level, as determined by the 1903 adjustment. The initial point of this list is a bench mark of flying levels on Ocmulgee River.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

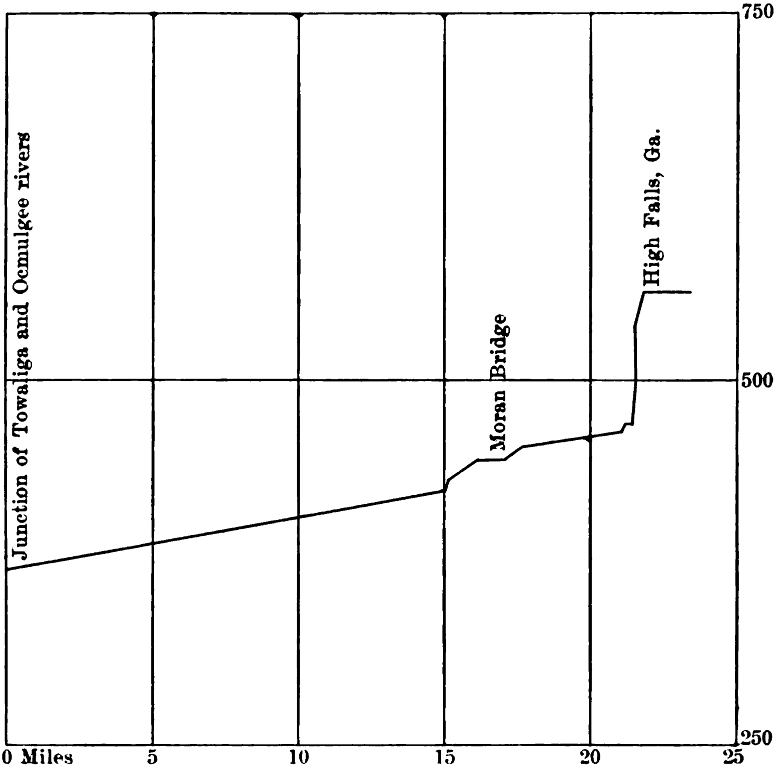


FIG. 9.—Profile of Towaliga below Highfalls, Ga.

Elevations on Towaliga River from mouth, near Berner, to Highfalls.

Distance in miles.		Elevation in feet.
0.0	Towaliga River, mouth of, on south side between railroad track and river, nail in root of water oak	379.34
.0	Surface of water	367
1.7	Lamars Bridge, near east end of, nail in root of beech tree	381.99
1.7	Surface of water	371
2.2	Small creek on west bank, mouth of, nail in root of ash tree	377.38
2.2	Surface of water	373
3.7	Surface of water	376
4	West bank, 50 feet from river, nail in root of large pine tree	412.45
4	Surface of water	379
4.6	Surface of water	382
6	Hunting Shoal Bridge, stone pier, on north end of bridge, iron bolt	412.80
6	Surface of water	386
7	North bank, 10 feet from river, twin water oak, nail in root of	399.49
7	Surface of water	393

Elevations on Towaliga River from mouth, near Berner, to Highfalls—Continued.

Distance in miles.		Elevation in feet.
8.8	Jacksons Bridge, west bank of river, large poplar tree, nail in root of..	409.84
8.8	Surface of water	395
9.5	Surface of water	377
10.5	West bank of river, creek, 100 yards above mouth of, 10 feet from river, nail in root of pine tree	416.15
10.5	Surface of water	400
11.8	Wilsons Bridge, 10 feet below east approach, nail in root of water oak..	421.06
11.8	Surface of water	406
12.3	West bank, on water oak	431.01
12.3	Surface of water	410
13.3	North and South forks of North Fork, 100 yards above junction of, nail in root of birch tree	416.93
13.3	Surface of water	414
14	Foot of shoals, surface of water	418
14.1	Head of shoals, surface of water	421
15	Foot of shoals, surface of water	422
15.1	Head of shoals, surface of water	428
15	Opposite shoals, north bank, nail in root of birch tree	432.23
15.5	Foot of shoals, surface of water	429
15.6	Head of shoals, surface of water	434
16	Morans Bridge, on north bank, 20 feet east of, nail in root of white oak.	443.61
16	Foot of shoals, surface of water	437
16.1	Head of shoals, surface of water	439
17.4	Opposite shoals, nail in root of willow	449.74
17.4	Surface of water	443
17.5	Foot of shoals, surface of water	446
17.5	Head of shoals, surface of water	450
18	Tobes Creek, mouth of, nail in root of pine	457.48
18	Surface of water	452
18.5	Foot of shoals, surface of water	452
.0	Head of shoals, surface of water	454
18.7	Small shoals, surface of water	455
.0	Head of small shoals, surface of water	457
19.2	Branch, south bank, 20 feet above mouth of, nail in root of birch tree...	462.60
21.2	Long shoals, foot of, south bank, nail in white oak tree	474.31
21.2	Surface of water	466
21.2	Highfalls Shoals, foot of, surface of water	492
21.3	Highfalls, head of Highfalls Shoals, surface of water	524
21.3	Highfalls, wagon bridge over Towiliga River, west side north approach to, top of iron bolt	563.32
21.7	Old dam, opposite, head of long shoals, surface of water	561
.0	Highfalls, high-water mark	561

CHATTAHOOCHEE RIVER FROM CHESTATEE TO SAUTEE, GA.

A survey of the upper Chattahoochee River between Chestatee and Sautee, Ga., a distance of 55 miles, was made during July and August, 1903. Between these two points a fall of 387 feet was found, the greater part of which is above the mouth of Soque River. During the survey 25 bench marks were established and 90 water-surface elevations determined. The plane-table sheets were plotted on a scale of 1:22,500. The original elevations for the levels were based upon an assumed elevation near Gainesville, Ga., but, as published herein, they have been reduced to mean sea level.

Above the mouth of Chestatee River for 10 miles are a number of small shoals aggregating a fall of 28 feet. Ten miles above the mouth of the Chestatee, Little River empties from the north, and at this point are the first good shoals, where there is a fall of 7 feet in a distance of 300 yards. A quarter of a mile above this point the North Georgia Electric Company is constructing a dam 36 feet high, which is to supply electric power. The backwater from this dam will extend 8 miles upstream, to just above Clarks Bridge. One half mile above this point is a shoal having a 9-foot fall in half a mile.

Just above this shoal are Reynolds Shoals, with a fall of 6 feet in 250 yards. There is a good power site at this point, as the banks and bottom are hard rock. From here to Mud Creek, 3 miles, there is a uniformly distributed fall of 15 feet, while just above the mouth of Mud Creek there is a good dam site. A dam here would be about 300 feet long, but the height could be 40 to 50 feet or more, if desired.

The next shoal of importance is Mountain Island Shoal. It gives a fall of 8 feet in half a mile. Here the river flows around the island between banks 100 feet high. A dam at the lower end would be 300 feet long. Perkins Shoals come next, 2 miles upstream, with a fall of 6 feet, and just above them is a shoal with a 7-foot fall. These could be used together.

From here to the mouth of Soque River is a uniform fall of 11 feet, and just above the mouth of the Soque there is a fall of 8 feet in 650 feet. For the next 3 miles there is a continuous succession of shoals, with a fall of 74 feet. The river flows in a narrow gorge of hard, unseamed rock, and at several points dams could easily be constructed. Above this point the river narrows very greatly, and is full of small shoals as far as Nacoochee Valley. From the valley to the end of the survey there are no falls or shoals.

Nacoochee Valley is very fertile and grain and grasses are raised. A large quantity of timber is still standing along the river, especially in the upper half of the valley.

The elevations in the following list are based upon an aluminum tablet at Nacoochee, marked "1349 Atlanta," in a ledge of rock 200 feet west of ford of Chattahoochee River, the elevation of which is now accepted as 1,348.269 feet above mean sea level.

The adjustment of this line was accomplished in conjunction with leveling on Chestatee and Soque rivers, tied at Willow and Clarksville, respectively, and by an extra check at Pole to primary-level circuits, and accords with the 1903 adjustment of the precise-level net.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

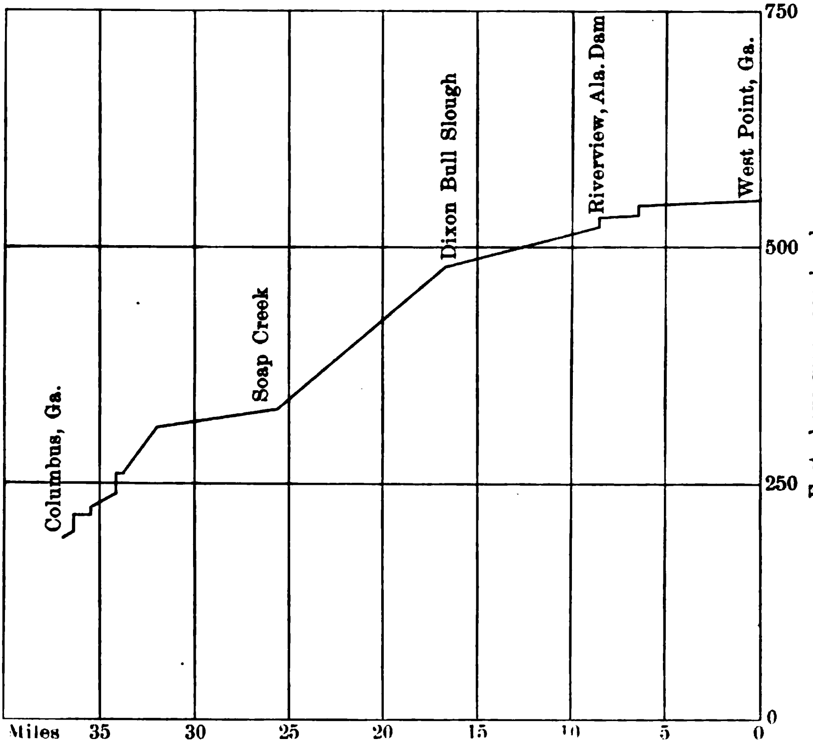


FIG. 10.—Profile of Chattahoochee River from Nacoochee to junction with Chestatee River, Ga.

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee.

Distance in miles.		Elevation in feet.
0.0	Near Keith's bridge, mouth of Chestatee River, on nail in root of walnut tree	964.37
.0	Surface of water	950
.0	Foot of shoals, surface of water	950
.0	Head of shoals, surface of water	956
1.7	On nail in root of walnut tree, north bank of river	989.71
3.7	Foot of shoals, surface of water	960
3.7	Head of shoals, surface of water	963

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee—Continued.

Distance in miles.		Elevation in feet.
5.7	Small shoals, edge of public road opposite, nail in root of large walnut tree	985.61
5.7	Small shoals, surface of water	965
6.2	Surface of water	966
6.8	Iron bridge, nail in root of large walnut tree	980.26
6.8	Surface of water	967
6.8	Foot of shoals, surface of water	967
7.3	Head of shoals, surface of water	972
8.3	Thompson Bridge, nail in root of large walnut tree	998.36
8.3	Surface of water	977
9.4	Little River, mouth of, foot of shoals, surface of water	978
9.4	Head of shoals, surface of water	984
10	North Georgia Electric Company's new dam, 100 yards below, north side of bluff, nail in root of white oak	1,004.04
10	Surface of water	985
11	Chattahoochee Park, on east side and at sharp bend of river, nail in birch tree	1,004.27
	Foot of shoals, surface of water	996
	Head of shoals, surface of water	1,010
12.2	New Bridge, near Gainesville, near small store building, large oak tree, spike in root of	1,028.32
12.2	Surface of water	1,011
13.2	South bank of river, 6 feet from water, willow tree, nail in root of	1,014.94
13.2	Surface of water	1,012
13.9	Foot of shoals, surface of water	1,012
	Head of shoals, surface of water	1,014
16.2	Clarks Bridge, east side of river, large maple tree, nail in root of	1,039.81
16.2	Surface of water	1,017
17.2	Small bluff, north side of river, poplar tree, nail in root of	1,045.27
17.2	Surface of water	1,020
	Head of shoals, surface of water	1,024
19.2	Red oak tree, nail in root of	1,043.29
19.2	Foot of shoals, surface of water	1,025
19.5	Foot of shoals, surface of water	1,028
	Head of shoals, surface of water	1,332
21.2	Savage Ferry, nail in notch of oak post	1,051.30
21.2	Surface of water	1,034
22.2	Left bank of river, nail in root of birch tree	1,050.46
22.2	Surface of water	1,037
23.9	North bank of river, nail in root of water-oak tree	1,046.76
23.9	Surface of water	1,038

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee—Continued.

Distance in miles.		Elevation in feet.
23.9	Head of shoals, surface of water	1,040
24.9	Seven Island shoals, opposite foot of, large poplar tree, nail in root of.	1,066.94
	Foot of shoals, surface of water	1,040
	Head of shoals, surface of water	1,044
25.6	Flat Creek, 1 mile above mouth of, nail in root of poplar tree	1,045.84
25.6	Surface of water	1,045
26.5	Lulu bridge, 60 feet below, on north bank of river, red oak tree, nail in root of	1,065.68
26.5	Surface of water	1,049
28.8	Walnut tree in large open bottom, left bank of river, nail in root of.	1,076.23
	Surface of water	1,053
29.8	Belton bridge. 100 yards below, right bank of river, walnut tree, nail in root of	1,076
29.8	Surface of water	1,056
31.8	Right bank of river, pine tree, nail in root of	1,092.99
31.8	Foot of shoals, surface of water	1,061
31.9	Head of shoals, surface of water	1,069
32.6	Nail in root of birch tree	1,085.79
32.6	Surface of water	1,070
	Foot of shoals, surface of water	1,071
	Head of shoals, surface of water	1,073
33.1	Head of shoals, on side of bluff, large pine, opposite, nail in root of	1,092.83
33.1	Surface of water	1,082
33.2	Harrisons Shoals, foot of, surface of water	1,084
34.1	Harrisons Shoals, opposite, nail in root of oak tree	1,101.70
34.1	Harrisons Shoals, surface of water	1,087
	Harrisons Shoals, head of, mouth of Mossy Creek, surface of water	1,087
34.2	Mountain Island Shoals, foot of, surface of water	1,088
	Head of shoals, surface of water	1,096
34.5	Head of shoals, opposite, nail in root of white oak	1,109.78
35.2	Foot of shoals, surface of water	1,101
35.2	Head of shoals, surface of water	1,106
35.2	Perkins Shoals, opposite foot of, nail in root of water oak	1,113.68
35.2	Perkins Shoals, foot of, surface of water	1,107
	Perkins Shoals, head of, surface of water	1,113
37.3	Foot of shoals, surface of water	1,115
	Head of shoals, surface of water	1,123
37.4	Head of shoals, north bank of river, opposite, nail in root of black-gum tree	1,127.76
38.2	Foot of shoals, surface of water	1,127
38.2	Head of shoals, surface of water	1,130

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee—Continued.

Distance in miles.		Elevation in feet.
38.3	Duncan Bridge, 30 feet below, nail in red-oak tree	1,148.90
38.4	Foot of shoals, surface of water	1,131
38.6	Head of shoals, surface of water	1,135
38.6	Head of shoals, opposite, nail in root of water oak	1,155.41
39.3	Soque River, south bank, at mouth, nail in root of birch tree	1,147.82
39.3	Surface of water	1,137
39.3	Soque River, mouth of, in forks of river, nail in root of pine stump	1,148.86
39.3	Surface of water	1,137
39.6	Head of shoals, surface of water	1,144
39.8	Foot of shoals, surface of water	1,149
40	Head of shoals, surface of water	1,159
40	Head of shoals, opposite, on west bank of river, nail in root of red oak	1,165.20
40.5	Long shoals, head of, surface of water	1,178
40.8	Foot of shoals, surface of water	1,178
	Head of shoals, surface of water	1,216
41.8	Head of shoals, root of hickory tree	1,222.10
42.3	Irwins Bridge, 10 feet below, left bank of river, nail in root of poplar tree	1,223.37
42.3	Surface of water	1,216
42.6	Irwins bridge, just above, surface of water	1,222
43.2	Head of shoals, surface of water	1,228
43.5	Foot of shoals, surface of water	1,229
	Head of shoals, surface of water	1,242
43.5	Blue Creek, surface of water	1,243
43.6	Blue Creek, 100 yards above mouth of, in fork, nail in root of red oak tree	1,256.09
44.2	Amos Ford, on west bank, large birch tree, nail in root of	1,256.09
44.2	Surface of water	1,244
44.5	Surface of water	1,247
45	Head of shoals, surface of water	1,250
46	Allens Bridge, west end of, red oak tree, nail in root of	1,266.49
46	Surface of water	1,256
	Head of shoals, surface of water	1,259
46.8	Foot of shoals, surface of water	1,260
	Head of shoals, surface of water	1,263
46.8	Head of shoals, opposite, nail in root of birch tree	1,264.18
47.3	Foot of shoals, surface of water	1,271
	Head of shoals, surface of water	1,274
47.5	Shoals, opposite head of, nail in root of pine tree	1,280.73
48.5	Foot of shoals, surface of water	1,276

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee—Continued.

Distance in miles.		Elevation in feet.
49	Head of shoals, surface of water	1,280
49	Shoals, red oak opposite head of, nail in root of	1,285.53
49	Head of shoals, surface of water	1,288
49.2	Sharp bend of river, water oak tree, nail in root of	1,304.53
49.2	Surface of water	1,292
50.5	Suspension footbridge, poplar tree at, nail in root of	1,305.97
50.5	Surface of water	1,297
51.8	Foot of shoals, surface of water	1,299
	Head of shoals, surface of water	1,306
53	Sautee Creek, near mouth of, in Nacoochee Valley, surface of water	1,309
55	Sautee Creek, ford near mouth, surface of water	1,339
55	Nacoochee post-office, 200 feet west of, ford of Chattahoochee River, 6 feet above surface of road, on ledge of rock, aluminum tablet marked "1349 Atlanta"	1,348.269

CHATTAHOOCHEE RIVER FROM CHATTAHOOCHEE TO FRANKLIN, GA.

A survey of the middle Chattahoochee River was made between Chattahoochee and Franklin, Ga., a distance of 65 miles. The elevations for this survey were based upon the United States Geological Survey bench mark at Chattahoochee, Ga., and the plane-table sheets were plotted on a scale of 1:22,500.

In the lower section of the river for 21 miles the Chattahoochee is without shoals or rapids until Redmens Shoals are reached, where there is a fall of 2 feet. The next shoals, Maderia Shoals, 11 miles farther downstream, have a fall of 6 feet in half a mile. Here, on the west side, is a large bluff of hard rock, and on the east side are flat bottom lands. The water is very shallow, and the stream has a rocky bottom. A dam here would be about 600 feet long, and to be made of sufficient height to develop any amount of head would flood valuable bottom lands above.

Below Maderia Shoals the river runs over small riffles of 1 to 2 feet until the Central of Georgia Railroad bridge is reached, and for 5 miles below this point there is practically no fall until McIntosh Shoals are reached, where there is a fall of 8 feet in a quarter of a mile. The river here runs through broken country, with high banks on both sides, showing good exposures of hard rock. A dam here would be 600 feet long, but several rocky islands would probably reduce the cost of construction. The dam could be 25 feet high or more if necessary.

Seven miles farther down the river are Fishtrap Shoals, with a 6-foot fall in a quarter of a mile. A dam here would be 700 feet long, as the west bank is low. Two miles downstream is the beginning of Bushhead Shoals, the best dam site on this section of the river. Here there is a fall of 7 feet, but added to the 5 feet just above and the 6 feet of Fishtrap Shoal, a total fall of 19 feet could be obtained in a distance of 5 miles. A dam built here would be 650 feet long and could be of any desired height. Good rock is exposed on each bank. Two flourishing towns, Newnan and Carrollton, which are about 15 miles from here, in opposite directions, would utilize this power. One mile below is a small 4-foot shoal, where the banks of the river are very flat.

At the mouth of Centralhatchee Creek, 2 miles below, is the last shoal, which has a 2-foot fall. It does not offer a good opportunity for development, owing to the low and extensive bottom lands on the north side of the river. This section of the river has a width of about 300 feet, but in some places widens to over 1,000 feet.

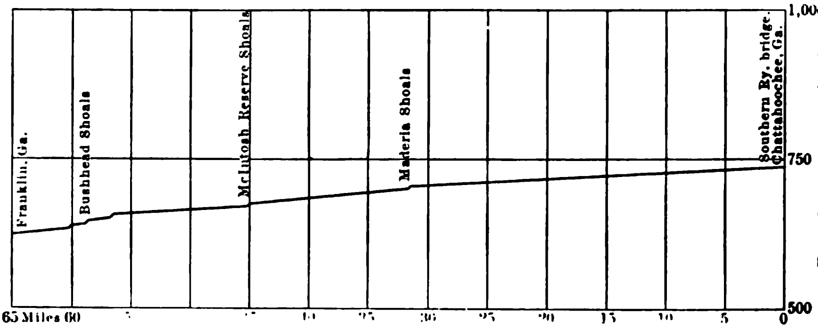


FIG. 11.—Profile of Chattahoochee River from Chattahoochee to Franklin, Ga.

Valuable and extensive bottom lands are under high cultivation, principally cotton and corn being raised, but the transportation facilities are very poor. The overflow from the river several times a year spreads a slimy sediment over the bottom which seems to act as a rich fertilizer.

For 4 miles below Chattahoochee there are valuable clay beds on the south side of the river, which have been excavated to a depth of 10 feet for brick manufacture.

The elevations in the following list are based on an aluminum tablet at the Washington street entrance to the State capitol building at Atlanta, marked "1050 M C," the elevation of which is now accepted as 1,049.546 feet above mean sea level. The line is adjusted to accord at each end, Oakdale and Franklin, with corrected primary elevations in accord with the 1903 adjustment.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Chattahoochee River from Chattahoochee to Franklin.

Distance in miles.		Elevation in feet.
0.0	Oakdale, in front of station, main track, top of south rail	809.20
.0	Surface of water	740
.5	Left bank of river, on root of willow tree	741.82
.5	Surface of water	739
1.6	Mason and Turner Ferry, near east approach to, on root to hickory tree	754.38
1.6	Surface of water	738
3.4	Old ferry, 10 feet from left bank, on root of sycamore tree	751.35
3.4	Surface of water	736
4.1	Left bank, 20 feet above bridge, on root of water oak	752.94
4.1	Surface of water	735
5.4	Left bank, 40 feet from river, on root of walnut tree	755.10
5.4	Surface of water	732
6.4	Left bank, 30 feet from river, on root of walnut tree	746.41
6.4	Surface of water	730
7.4	Left bank, 40 feet from river, on root of walnut tree	752.90
7.4	Surface of water	729
8.4	Left bank, 20 feet from river, on root of sweet gum tree	742.16
8.4	Surface of water	727
10.3	Adaholts Ferry, mouth of Sweetwater Creek, opposite, on root of large sycamore tree	744.73
10.3	Surface of water	726
11.3	Left bank, 30 feet from river, on root of large walnut tree	747.58
11.3	Surface of water	725
12.8	Dupree Ferry, left bank, 15 feet from river, on root of elm tree	738.09
12.8	Surface of water	723
14.8	Left bank, 70 feet from river, on root of walnut tree	746.29
14.8	Surface of water	721
16.6	Camp Creek, mouth of, on root of ash tree	736.13
16.6	Surface of water	720
17	Left bank, 20 feet from river, on root of walnut tree	741.78
17	Surface of water	719
17.9	Campbellton Ferry, 10 feet from river, left bank, on root of sycamore tree	728.69
17.9	Surface of water	719
20.6	Brock's ferry, 10 feet from river, left bank, on root of white oak tree	730.49
20.6	Surface of water	716
21.2	Redmens Shoals, left bank, 10 feet from river on root of sycamore tree	728.58
21.2	Surface of water	716
21.3	Redmens Shoals, foot of, surface of water	714
21.7	Pea Creek, mouth of, surface of water	714

Elevations on Chattahoochee River from Chattahoochee to Franklin—Continued.

Distance in miles.		Elevation in feet.
22	Rivertown Ferry, left bank, 10 feet from river, on root of sycamore tree	720.64
22	Surface of water	714
23.4	Pumpkintown Ferry, left bank, 15 feet from river, on large birch tree	727.94
23.4	Surface of water	712
24.5	Bear Creek, mouth of, on root of poplar tree	730.35
24.5	Surface of water	712
25.6	Left bank, 40 feet from river, on root of walnut tree	725.50
25.6	Surface of water	710
28.1	Defer's ferry, left bank, 15 feet from river, on large birch tree	722.92
28.1	Surface of water	709
29.6	Jones Ferry, left bank, 15 feet from river, on root of pine tree	718.60
29.6	Surface of water	706
30	Ballard Shoals, 10 feet from river, left bank, on root of willow tree	711.13
30.9	Ballard Shoals, head of, surface of water	705
31.1	Ballard Shoals, foot of, surface of water	704
31.4	Madeira Shoals, head of, surface of water	704
31.8	Madeira Shoals, opposite, on right bank, on root of white oak, side of rock bluff	716.81
31.8	Madeira Shoals, surface of water	702
32.1	Wolf Creek, mouth of, foot of Madeira Shoals, surface of water	698
33.4	Hutchinson's ferry, right bank, 20 feet from river, on root of maple tree	709.12
33.4	Surface of water	694
35.1	Long Island, upper end of, head of shoals, surface of water	692
35.1	Right bank, head of shoals, in root of pine tree	709.11
36	Long Island, opposite lower end of, foot of shoals, nail in root of water oak tree	703.37
36	Surface of water	689
37.5	Snake Creek, right bank, 10 feet from river, 100 yards above mouth, on root of willow tree	696.72
37.5	Surface of water	688
38.6	Moores Ferry, right bank, on root of large birch tree	702.85
38.6	Surface of water	686
39.2	Shoals, head of, surface of water	685
39.3	Shoals, foot of, surface of water	684
40.1	Central, of Georgia, Railroad bridge over river, right bank, 40 feet above bridge, on root of willow tree	692.12
40.1	Surface of water	684
40.1	Shoals, foot of, surface of water	683
40.7	Opposite right bank, nail on root of poplar tree	699.76
40.7	Surface of water	682

Elevations on Chattahoochee River from Chattahoochee to Franklin—Continued.

Distance in miles.		Elevation in feet.
41.4	Reese's ferry, right bank, on root of ash tree	693.86
41.4	Surface of water	682
41.7	Head of Shoals, surface of water	682
41.8	Foot of Shoals, surface of water	681
42.6	Fridell Shoals, head of, surface of water	680
42.7	Fridell Shoals, foot of, surface of water	679
43	Foot of bluff, right bank of river, nail in root of sweet gum tree	684.36
43.6	Hanson Shoals, head of, surface of water	678
43.9	Houston Ferry, nail in root of catalpa tree	684.02
43.9	Surface of water	677
44.9	McIntosh Reserve Shoals, head of, surface of water	676
45.4	McIntosh Reserve Shoals, foot of, right side of bank, nail in root of sweet gum tree	679.49
45.4	McIntosh Reserve Shoals, foot of, surface of water	668
46.1	Culpepper, mouth of, on root of red oak tree	678.04
46.1	Surface of water	667
49	Whooping Creek, mouth of, nail in root of birch tree	670.70
49	Surface of water	664
50	Brown's ferry, right bank, nail in root of walnut tree	661.96
50	Surface of water	662
50.7	Yellow Dirt Creek, right bank, nail in root of sweet gum tree	679.80
50.7	Surface of water	662
50.9	Yellow Dirt Creek, mouth of, surface of water	660
53.1	Hollingsworth Ferry, right bank, nail in root of water oak tree	673.31
53.1	Surface of water	658
55	Pink Creek, mouth of, surface of water	658
55.3	Right bank, on nail in root of sweet gum tree	664.97
55.3	Surface of water	658
56.3	Fishtrap Shoals, head of, surface of water	657
56.9	Fishtrap Shoals, right bank, opposite center of shoals, elm tree, nail in root of	670.26
56.9	Fishtrap Shoals, surface of water	652
57.5	Fishtrap Shoals, foot of, surface of water	648
58.5	Bushhead Shoals, opposite upper island, nail in root of birch	653.32
58.5	Bushhead Shoals, head of, surface of water	645
59	Bushhead Shoals, foot of, on side of bluff, nail in root of white oak	648.15
59	Bushhead Shoals, foot of, surface of water	638
60	Head of shoals, surface of water	638
60.2	Foot of shoals, surface of water	634
60.8	Head of shoals, surface of water	634
61	Foot of shoals, surface of water	632
62	Head of shoals, surface of water	632

Elevations on Chattahoochee River from Chattahoochee to Franklin—Continued.

Distance in miles		Elevation in feet.
62.2	Foot of shoals, surface of water	628
63.8	Centralhatchee Creek, opposite mouth of, nail in root of birch	633.49
63.8	Surface of water	628
64	Foot of shoals, surface of water	627
64.5	Franklin, wagon bridge, surface of water	626
64.7	Franklin, on rivet on top left iron pier of east approach of wagon bridge	655.17
65	Franklin, in south side of court-house, bronze tablet marked "695 A"	694.742

CHATTAHOOCHEE RIVER FROM WEST POINT TO COLUMBUS, GA.

Chattahoochee River was surveyed from West Point to Columbus, Ga., a distance of 37 miles, in which there is a fall of 361 feet. During the work 5 bench marks were established and 35 water-surface elevations obtained. The survey was plotted on the scale of 1: 22,500, and was accompanied by a flying-level line based on a United States Geological Survey tablet at West Point, Ga.

For 4 miles below West Point the river is sluggish. At Langdale, Ala., there is a wing dam with 9 feet head, operating a knitting mill. The dam is loosely built of light lumber, connecting a number of small islands, and a large amount of water goes to waste.

Probably the best site for a permanent structure at Langdale is about one-half mile below the present mill, where a head of 18 feet would back water to just below West Point. A dam as proposed above would not, except in time of flood, spread the backwater beyond the present banks of the river.

Between Langdale and Riverview, where there is another knitting mill, there is a continuous network of small islands. At Riverview there is a 9-foot wing dam similar to that at Langdale, but it furnishes even less water, as the eastern channel is broader.

From Riverview to Columbus the river is one continuous shoal, and the choice of sites for dam construction rests on minor details rather than amount of power.

Some of the best sites are just below Houstons Ferry, 3¼ miles from Riverview, where a 24-foot dam would have good ledge-rock foundations for the 480 feet of river bed, while the ordinary red clay of the region appears on the banks.

Three miles farther downstream, about 1 mile below Blantons Ferry, is another site, but a dam here would flood a good deal of bottom land. For 4 miles below here is one of the swiftest and roughest parts of the river. There is a good site at the end of the stretch, just below the Big Bull Slough, and another one-third of a mile above Bartlett's old ferry. The former could probably be developed into a valuable plant, supplying power to West Point, Lanett, Hamilton, Opelika, and a score of smaller towns, all less than 25 miles from this point. A dam probably could be built here with a head of 70 feet. The river bottom is ledge rock, with some bowlders, and the shores are of the same rock covered with more or less soil. A dam 70 feet high would back the water nearly to Mountain Oak Creek. Many of the islands in the river would be flooded. Some of them are large and cultivated to some extent. There would also be some flooding of bottom lands on both sides of the river, but no lands of pronounced value would be destroyed.

About 5¾ miles farther downstream, at what is known locally as Goats Rock, a dam very similar to the above could be constructed. The shore lines are very precipitous and ledge rock outcrops on both banks. A head of 70 feet would utilize all the available power between this point and the proposed dam 5¾ miles above.

Seven and one-half miles below is the beginning of what is known as the old Clapp factory falls. This is one of the best rapids on the river. Unfortunately, the river is exceptionally wide and the construction of a dam would be expensive. The old mill derived its power by means of a wing dam which has not been used upward of fifteen years. A dam here, backing the water up to Goat Rock, and a canal carrying it to the foot of the falls, will give a total head of about 77 feet. The river bottom is ledge rock, and the shores are the same covered with several feet of soil.

One and one-fourth miles below the old Clapp factory is the dam of the Columbus Power Company. This dam has a head of 32 feet, developed by a stone concrete dam, below which the tailrace has been deepened and separated from the river by a stone wall. Part of the power is utilized by the large cotton mill of the company, situated on the east bank of the river. The balance is distributed about the city of Columbus.

One and one-fourth miles farther down the stream is what is called the city mill dam, with 9½ feet head. It is a wooden structure and needs constant attention, furnishing power to the city of Columbus and to a gristmill. Three-fourths of a mile below is a stone dam kept in good repair and owned by the Eagle and Phoenix Company, one of the largest cotton manufacturing companies in the South. Just below this dam is the head of navigation for steamboats.

The elevations in the following list are based upon a bronze tablet in west abutment of Altanta and West Point Railroad bridge over Chattahoochee River at West Point. The elevation of this, as determined by a net of primary levels, extended from Rome, Ga., a point on the precise-level net, is 573.193 feet above mean sea level, in accord with the 1903 corrected elevation of that place.

The leveling was done under the direction of I. T. Fitch, field assistant, by W. H. Sallee, levelman.

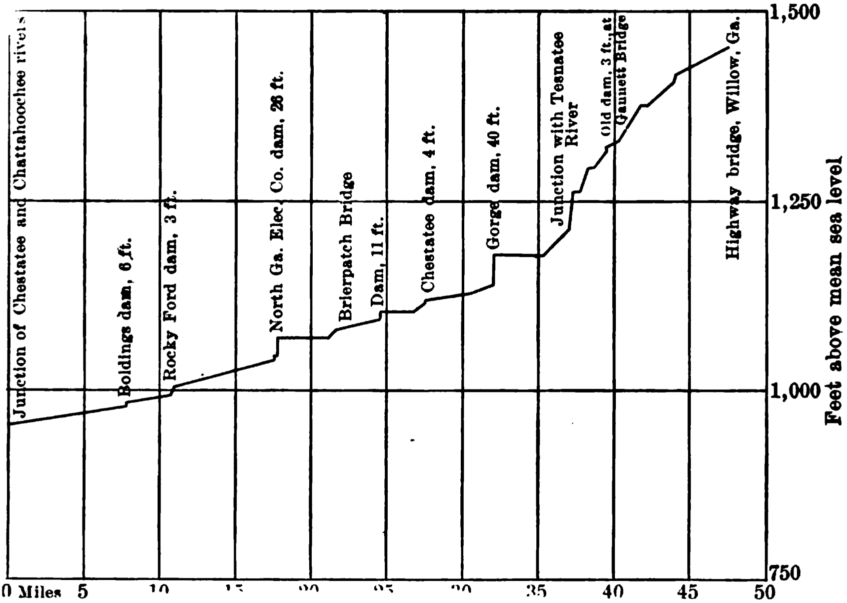


FIG. 12.—Profile of Chattahoochee River from West Point to Columbus, Ga.

Elevations on Chattahoochee River from West Point to Columbus, Ga. (single spur line)

Distance in miles.		Elevation in feet.
0.0	West Point, in west abutment of Atlanta and West Point Railroad bridge over Chattahoochee River, bronze tablet marked "573 A". .	573.193
.0	Highway bridge, surface of water	551
.0	Tidewater elevation corresponding to zero of local hydrographic station	549
.0	West Point, opposite, in Alabama, United States engineers' bench mark, 1,000 feet north of highway bridge, 100 feet east of road intersection, west bank of river, 75 feet from water, iron monument sunk in ground	564.28
3.1	Long Cane Creek, surface of water	549
6	Langdale, Ala., 90 feet south of Moores Creek, in factory lawn between factory and track, top of hydrant	548.54
6	Langdale, mill pond at, surface of water	542.1
6	Langdale, below dam, surface of water	533
8.6	Riverview, mill pond, surface of water	532
8.6	Riverview, below mill pond, surface of water	522
8.6	Riverview, opposite, in Alabama, northwest corner of cotton mill, 35 feet southwest of, 50 feet south of dam, top of double-orifice hydrant	534.94

Elevations on Chattahoochee River from West Point to Columbus, Ga. (single spur line)—Continued.

Distance in miles.		Elevation in feet.
12	Houstons Ferry, surface of water	497
14.4	Blantons Ferry, west side of river, 200 feet from edge of water, 25 feet east of poplar tree, wagon road, top of knob, south side of blazed tree	508.74
16.6	Dixons Ferry, surface of water	483
20.3	Bartletts old ferry, 50 feet northwest of west bank of river, top of ledge, rock 18 feet from water	404.78
23.7	Mulberry Creek, Georgia, surface of water	363
34.7	Columbus Power Company, mill pond, surface of water	260
34.7	Columbus Power Company, below pond, surface of water	240
35.9	Columbus, mill pond of city milldam, surface of water	226
	Columbus, below mill pond of city milldam, surface of water	216
36.1	Columbus, above Eagle and Phoenix Company dam, surface of water	216
36.1	Columbus, below Eagle and Phoenix Company dam, surface of water	200
37	Columbus, beneath highway covered bridge, surface of water	190
37	Girard, Ala., Broad and Sixth streets, southeast corner of intersection, bucket and windlass well, 45 feet east of, top of stone guard post at Wm. C. Bill's saloon	255.14

SOQUE RIVER BELOW CLARKSVILLE, GA.

Soque River was surveyed from its mouth, near View, Ga., to Clarksville, Ga., a distance of 8 miles. The levels were based on a line carried up Chattahoochee River from Gainesville, Ga., and the field sheets were platted on the scale of 1:22,500.

The first power is 5½ miles above its mouth and 1 mile below from Bert. Here there is an undeveloped fall of 6 feet in about 50 yards. The south bank is hard rock; the north bank is not very high, but seems to be solid rock. The best site for a dam is probably at the lower end of the falls. A dam here would be about 380 feet long and not over 7 feet high, or the water would back up over the lower end of more valuable shoals above.

At Bert, Ga., are the Porter Shoals, which have a drop of 48 feet—far the best waterfall on the river. A small wing dam develops power to operate Porter's woolen and cotton factory, 4 miles from Demorest, Ga., the nearest railroad point.

About 500 feet upstream is Porter's upper shoal, at which there is a 15-foot fall partly developed by a small dam, and which supplies power for factory No. 2 of the same company. A much greater head would be obtained here by increasing the size of the dam.

One and one-half miles above Bert is a splendid water-power site, known as the Old Factory Shoals, where there is a fall of 23 feet in a distance of 600 feet. There was a dam here at one time, but all signs of it have vanished. The river is about 350 feet wide and flows in several channels between small islands. Good sandstone outcrops on both banks.

Just above this point the river bottoms widen and the farming lands are better between here and Clarksville, the end of the survey, than any point on the river.

The elevations in the following list are based upon an aluminum tablet at the north side of east entrance to the court-house at Clarksville, marked "1372 Atlanta," the elevation of which is accepted as 1,371.991 feet above mean sea level, in accord with the 1903 adjustment of the precise-level net.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

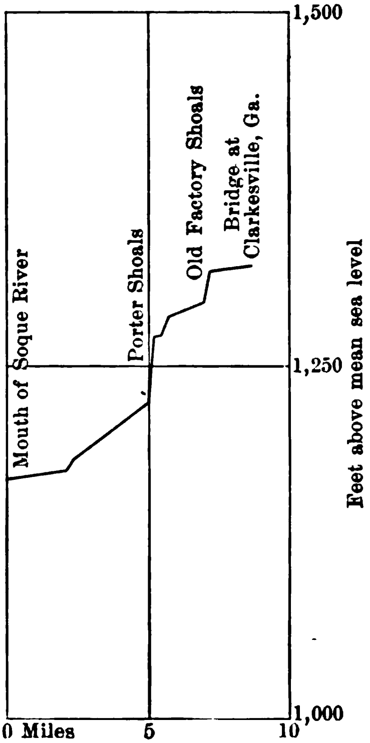


FIG. 13.—Profile of Soque River below Clarksville, Ga

Elevations on Soque River from near View to Clarksville, Ga.

Distance in miles.		Elevation in feet.
0.0	Soque River, south bank of mouth of, at junction of Soque and Chattahoochee rivers, birch tree, nail in root of	1,147.82
.0	Surface of water	1,137
1.6	McAllisters Bridge, near north end of, nail in root of white oak	1,156.30

Elevations on Soque River from near View to Clarkesville, Ga.—Continued.

Distance in miles.		Elevation in feet.
1.6	Surface of water	1,142
	Foot of shoals, surface of water	1,142
	Head of shoals, surface of water	1,149
4	Newbridge, hickory tree on north bank, nail in root	1,171.71
	Surface of water	1,152
4.1	Foot of shoals, surface of water	1,153
	Head of shoals, surface of water	1,156
4.7	Foot of shoals, surface of water	1,156
	Head of shoals, surface of water	1,162
5.6	Foot of shoals, surface of water	1,166
5.7	Head of shoals, surface of water	1,181
6.1	Porter's mills, foot of Porter Shoals, surface of water	1,189
6.1	Bert, head of Porter Shoals, surface of water	1,237
5.9	Bert, Porter Shoals, opposite head of shoals, water oak, nail in root of	1,189.07
6.1	Bert, near north end of wagon bridge, red oak tree, nail in root of	1,246.13
6.2	Bert, foot of upper shoals, surface of water	1,238
	Head of upper shoals, surface of water	1,253
6.3	Bert, Ga., 200 yards above factory, near river, on root of water oak	1,262.75
7.3	Foot of shoals, surface of water	1,261
7.3	Left bank of river, nail on root of sycamore tree	1,287.37
7.3	Surface of water, head of shoals	1,284
8.8	Clarksville, Habersham County court-house, on north side of east entrance, aluminum tablet marked "1372 Atlanta"	1,371.991
8.8	Surface of water	1,289

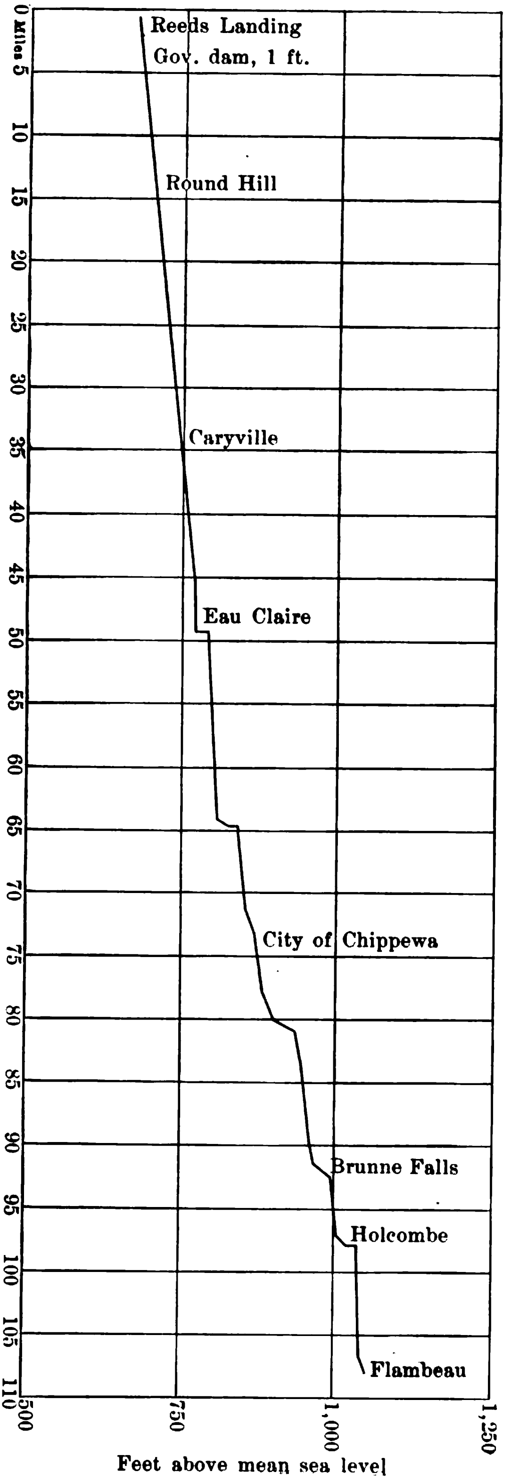
CHESTATEE RIVER BELOW WILLOW, GA.

Chestatee River was surveyed from Willow, Ga., to its mouth, near Chestatee, a distance of 47.7 miles.

A line of secondary levels was run, based on a primary bench mark of the United States Geological Survey, 2 miles north of Willow. The field sheets were platted on the scale of 1:22,500. During the course of the survey 40 bench marks were established and 98 water-surface elevations obtained.

For the first 8 miles the river traverses a very wild and broken country, and is only about 50 feet wide. There is not enough water to produce any considerable amount of power, although there is a fall of 124 feet.

At Gannett Bridge there is an old 3-foot dam which was used to furnish power for a gold-stamping mill, the machinery of which is now



PROFILE OF CHESTATEE RIVER BELOW WILLOW, GA.

ruined from disuse. This is about the north boundary of the Dahlonega gold field now under vigorous development.

One mile downstream is an unnamed shoal, with a fall of 30 feet in 0.6 of a mile. The river runs between very steep banks of hard, unseamed rocks, and a 200-foot dam could be constructed here, abundant material being easily accessible.

Just below Grinnells Ford is a splendid site, where the river suddenly drops 47 feet in about 150 yards and passes through a narrow gorge. The river bed is of broken rock, and a dam at this point would be about 200 feet long.

About 2 miles farther down is a drop of 11 feet in 100 yards. The river runs through a narrow gorge, but just above the valley widens enough to make a good storage basin. A dam would be about 225 feet long and could be built to almost any desired height. A pyrites mine here employs 50 men. Four miles below the Crown Gold Mining Company is erecting a 40-foot dam, known as the Gorge dam, to run hydraulic pumps for two placer mines.. This dam will back up the water for 2½ miles and will cover a number of small shoals.

The river below here runs swiftly, but without important shoals for about 3½ miles. It then enters the back water from Chestatee dam, which is 4 feet high, and supplies power for a gristmill, cotton gin, and hydraulic pump.

Three miles farther down is a gold-stamping mill, the power for which is supplied by an 11-foot dam, which backs the water up as far as Iron Bridge just below the Chestatee dam. Six miles farther down is a 26-foot dam, built by the North Georgia Electric Company, at Newbridge, Ga., which supplies power for the traction system and lighting of the city of Gainesville, Ga., 15 miles away. A smaller dam, 4 feet high, just below the main structure, furnishes power for a gristmill and cotton gin.

Below Newbridge, Ga., the river enters a more level country and runs with little fall to Bolden's bridge, 9 miles below, passing a 3-foot dam, which is used to operate a small flouring mill, and a 6-foot dam, which supplies power for a large gristmill.

In the remaining 8 miles there are no shoals or opportunities for power development. The sand in the bed of the river contains a large amount of gold, and placer mining on a considerable scale is one of the occupations of the people throughout this whole region.

Nearly all of the important shoals which are undeveloped are controlled by the mining interests in the neighborhood. The upper part of the survey was through fairly heavy timber, but the lower end of the work was through land all under high cultivation. The river passes 3 miles from Dahlonega, the county seat of Lumpkin County.

The elevations in the following list are based upon a bronze tablet 2.5 miles north of Willow, in rock on west side of river at fork of road, marked "1529 Atlanta," the elevation of which is accepted as 1,528.649 feet above mean sea level, in accord with the 1903 adjustment of the precise-level net.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Chestatee River below Willow, Ga.

Distance in miles.		Elevation in feet.
2.5	Willow, 2.5 miles north of, on west side of river, at fork of road, in rock, bronze tablet marked "1529 Atlanta"	1,528.649
.0	Willow, near west end of bridge, walnut tree, nail in root of	1,461.37
.0	Surface of water	1,454
.25	Surface of water	1,449
1	Foot of shoals, opposite, west side of river, nail in root of maple tree	1,447.54
1	Head of shoals, surface of water	1,446
	Foot of shoals, surface of water	1,444
1.6	Head of shoals, surface of water	1,443
	Foot of shoals, surface of water	1,438
2.5	Head of shoals, surface of water	1,428
2.7	Foot of shoals, surface of water	1,422
3	Right bank and 10 feet from river, nail in root of red oak tree	1,437.94
3	Surface of water	1,416
3.7	Head of large shoals, surface of water	1,415.5
3.8	Foot of large shoals, surface of water	1,406
4	Shoals, opposite, right bank of river, nail in root of red oak	1,425.41
4	Surface of water	1,405
4.2	Foot of shoals, surface of water	1,399
4.7	Sharp bend of river, right bank, nail in root of red oak	1,404.53
4.7	Surface of water	1,394
4.9	Crooked Shoal, head of, surface of water	1,390
5.2	Crooked Shoal, foot of, surface of water	1,386
5.2	Head of shoals, surface of water	1,384
5.4	Foot of shoals, surface of water	1,378
5.4	Left bank of river, opposite shoals, large white oak, nail in foot of	1,388.79
6	Head of shoals, surface of water	1,377
6.4	Foot of shoals, surface of water	1,353
6.4	Foot of shoals, left bank, 60 feet below, nail in root of hickory	1,364.25
6.9	Head of shoals, surface of water	1,346
	Foot of shoals, surface of water	1,328
7.3	Small creek, mouth of, opposite center of shoals, spruce pine, nail in root of	1,335.59
8	Old dam, top of, surface of water	1,321
	Old dam, bottom of, surface of water	1,317
8.2	Gannett Bridge, 10 feet below, on left bank river, nail in red oak	1,318.35

Elevations on Chestatee River below Willow, Ga.—Continued.

Distance in miles.		Elevation in feet.
8.2	Surface of water	1,309
8.5	Old gold-stamping mill, foot of bridge at, surface of water	1,305
8.8	Head of shoals, surface of water	1,304
	Foot of shoals, surface of water	1,296
	Foot of shoals, opposite, left bank river, nail in root of sweet gum tree	1,303.10
9.4	Head of shoals, surface of water	1,293
9.9	Grinnells Ford, foot of shoals, surface of water	1,263
10	Grinnells Ford, in root of large birch tree, near ford, nail in root of	1,265.45
10.3	Head of shoals, surface of water	1,262
10.7	Tesnatee River, mouth of, foot of shoals, surface of water	1,215
10.7	Tesnatee River, mouth of, in fork between rivers, on side of rock bluff, in white oak tree, nail	1,231.37
11.1	Grinnell's lower ford, surface of water	1,209
11.2	Grinnell's lower ford, on right bank 100 yards below ford, point of large rock, chisel mark	1,218.11
11.2	Grinnell's lower ford, foot of shoals, surface of water	1,207
11.4	Head of shoals, surface of water	1,206
11.6	Foot of shoals, surface of water	1,201
11.6	Right bank of river, nail in root of hickory tree	1,214.34
11.7	Head of shoals, surface of water	1,200
11.9	Foot of shoals, surface of water	1,189
12.6	Head of shoals, surface of water	1,187
	Foot of shoals, surface of water	1,174
12.8	Right bank river, pine tree, nail in root of	1,183.54
13.5	Head of shoals, surface of water	1,169
	Foot of shoals, surface of water	1,163
14	White oak tree, nail in root of	1,166.95
14	Surface of water	1,160
14.6	Head of shoals, surface of water	1,155
	Foot of shoals, surface of water	1,150
14.9	Gorge dam, above, head of shoals, surface of water	1,149
15.8	Gorge dam, 40 feet below, right bank of river, nail in hickory tree	1,159.21
15.9	Gorge dam, below dam, foot of shoals, surface of water	1,138
16.4	Surface of water	1,133
17	Bearden's bridge, top of stone pier on west approach, iron bolt	1,150.10
17	Surface of water	1,130
17.6	Head of shoals, surface of water	1,125
17.8	Surface of water	1,122
20.2	Chestatee dam, top of, surface of water	1,119
20.2	Chestatee dam, foot of, surface of water	1,115
20.4	Iron Bridge, 60 feet below, beech tree, nail in root of	1,121.86

Elevations on Chestatee River below Willow, Ga.—Continued.

Distance in miles.		Elevation in feet.
	Iron Bridge, surface of water	1,109
20.6	Foot of shoals, surface of water	1,106
	Surface of water	1,105
22.8	Gold-stamping mill, top of dam, surface of water	1,104
	Foot of dam, surface of water	1,092
	Gold-stamping mill, persimmon tree near, nail in root of	1,114.62
23.9	Branch, near mouth of, nail in root of red oak	1,106.49
23.9	Surface of water	1,089
24.2	Foot of small shoals, surface of water	1,084
25.1	Brierpatch Bridge, south side of east approach, iron bolt	1,104.71
25.1	Surface of water	1,082
26.1	Head of shoal, surface of water	1,079
26.2	Foot of shoals, surface of water	1,075
26.8	Head of shoals, surface of water	1,070
27.9	Left bank of river, pine tree, nail in root of	1,079.43
30	Georgia Electric Company's dam, top of, surface of water	1,070
	Foot of dam, surface of water	1,043
30.2	Newbridge (post-office), west side, top of central bridge pier, bolt	1,060.43
	Newbridge, head of small dam, surface of water	1,043
30.2	Small dam, foot of, surface of water	1,039
31.3	East bank, 50 feet from river, nail in root of large pine	1,062.63
31.3	Surface of water	1,028
32.5	Head of shoals, surface of water	1,027
	Foot of shoals, surface of water	1,024
32.5	Pine tree opposite shoals, nail in root of	1,049.28
33.4	Yellow Creek, 50 yards below mouth of, nail in root of red oak	1,048.27
33.4	Surface of water	1,022
33.5	Surface of water	1,017
	Head of small shoals, surface of water	1,016
	Foot of small shoals, surface of water	1,014
34.7	Robinson's ford, 10 feet from river, nail in root of red oak tree	1,025.30
	Robinson's ford, surface of water	1,012
35.7	Rock Bluff, left bank of river, nail in root of oak tree	1,020.21
35.7	Surface of water	1,009
35.8	Foot of shoals, surface of water	1,005
36.7	Flour mill, top of dam, surface of water	1,003
	Dam, foot of, surface of water	1,000
36.9	Surface of water	993
38.5	Small creek, mouth of, surface of water	986
38.8	East bank of river, 40 feet from, nail in root of red oak	1,003.69
39.6	Bolden's bridge, 40 feet from east bank, stump near bridge, nail in root of	999.56

Elevations on Chestatee River below Willow, Ga.—Continued.

Distance in miles.		Elevation in feet.
39.8	Bolden's bridge, west side of east approach, top of, iron bolt......	1,001.28
39.8	Surface of water..	984
39.9	Mill, top of dam, surface of water..................................	983
	Mill, foot of dam, surface of water................................	977
40.8	Langleys Creek, east side, 40 feet below mouth, nail in root of red oak.	989.34
40.8	Langleys Creek, mouth of, surface of water........................	972
40.9	Surface of water..	970
42.6	East bank of river, nail in root of sycamore tree.................	974.48
42.6	Surface of water..	964
43.4	Surface of water..	963
44.6	River, 200 feet from, in open field, nail in walnut tree............	975.87
44.6	Surface of water..	960
45.6	Mouth of branch, near, 40 feet from east bank of river, nail in red oak tree..	981.76
47.7	Chestatee, Ga., near, at mouth of Chestatee River, near Keith's bridge, nail in root of walnut tree..............................	964.37

HIWASSEE RIVER FROM HIWASSEE, GA., TO APALACHIA, N. C.

Hiwassee River was surveyed from Hiwassee, Ga., to Apalachia, N. C., a distance of 63 miles. In that distance there is a fall of 707 feet. A line of secondary levels based on the United States Geological Survey bench mark at Hiwassee, Ga., was run. The field sheets were plotted on the scale of 1:22,500. During the course of the survey 39 bench marks were established and 119 water-surface elevations obtained.

There are no shoals of any consequence until just below Bell Creek, where there is one of 10 feet with good rock bottom and rock bluffs on the northeast side of the river. A dam could be constructed here with a length of about 200 feet.

One mile below Hayesville Bridge is a shoal with a fall of 18 feet in 1¼ miles, but no suitable place for a dam was noted.

One and one-half miles below, at Passmore Ford, is a shoal with a 21-foot fall in 1¼ miles and with a fairly good site for the construction of a dam. The bottom is rocky and there are rock bluffs on the south side of the river. The dam would be about 300 feet long.

Four and one-half miles below is the 12-foot dam of the Cherokee Lumber Company. This is a splendid site. A 40-foot structure would not back the water over 1½ miles and would not do any damage to cultivated lands.

Three miles below, at Island Ford, is a shoal with a 17-foot fall in

1 mile. This is an excellent dam site, as the bottom is rocky and there are hard-rock bluffs on either side. The dam would be 300 feet long. Building material can be easily obtained. Five miles below, and about 1 mile above Murphy, is a shoal with a 25-foot fall in 1¾ miles. A dam about 600 feet long could be built here.

One-third mile below Murphy, at the mouth of Valley River, is the head of a shoal 1¾ miles long with a fall of 25 feet. This is an excellent power site. The bottom is rocky; both sides are of hard rock. The dam would be about 500 feet long.

Seven and one-half miles below Murphy, at Shallow Ford, is a shoal with 14-foot fall in 1¼ miles. This offers an excellent site for a dam, as bottom and banks are rocky. The dam would be about 550 feet long. Three miles below Shallow Ford is a shoal with a 20-foot fall in 1½ miles. The dam here would be only about 400 feet long.

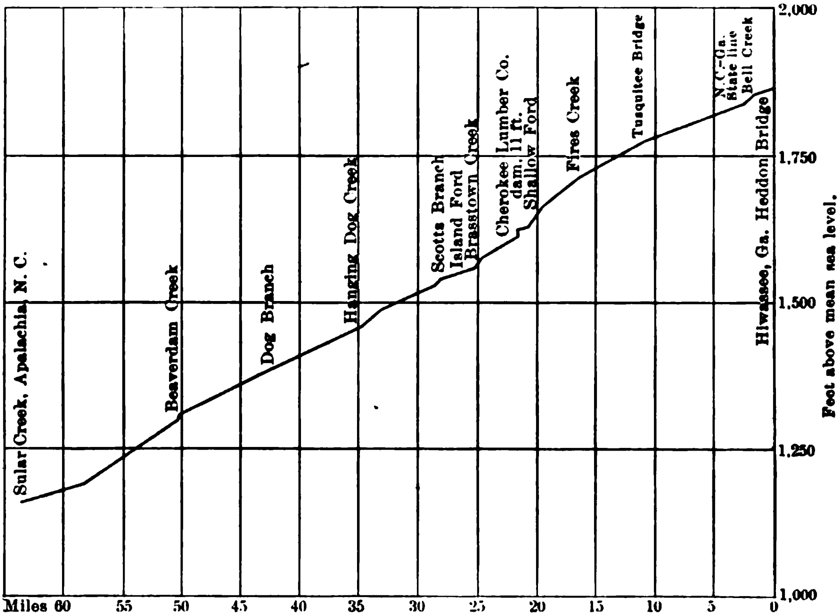


FIG. 14.—Profile of Hiwassee River from Hiwassee, Ga., to Apalachia, N. C.

Two miles below is a 23-foot shoal 1¾ miles long, where the river runs between steep hills. The dam here would be 600 feet long. Excellent building material is at hand.

From Chambers Creek to lower Shallow Ford, 6½ miles, the river has a fall of 15 feet per mile, and is almost a continuous shoal. There are several excellent dam sites. From Shoal Creek to Cane Creek, 2 miles, there is a shoal with a fall of 38 feet. This is a fine power site, with hard, rocky bottom and sides. A dam at this point would be about 700 feet long.

From Cane Creek down to the Tennessee State line (5 miles), the end of the survey, the river has a fall of 30 feet, with only a 7-foot shoal three-fourths of a mile between Kilpatrick Ferry and Taylor Ferry.

The elevations in the following list are based upon an aluminum tablet marked "1984 Atlanta" at the northeast corner of front vestibule of Towns County court-house, Hiwassee, Ga., the elevation of which is accepted as 1,983.634 feet above mean sea level. The leveling is adjusted with flying levels on Nottely River to accord with the 1903 adjusted elevation of primary bench mark at Blairsville and Hiwassee, Ga. From the mouth of Nottely River to Apalachia the leveling is a single spur line.

The leveling was done in 1903, under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

Elevations on Hiwassee River from Hiwassee, Ga., to Apalachia, N. C.

Distance in miles.		Elevation in feet.
0.0	Hiwassee, Towns County, court-house, at northeast corner of front vestibule, aluminum tablet marked "Atlanta, 1,984"	1,983.634
.3	Hiddon Bridge, 300 feet north of, edge of county road, white-oak tree, nail in west side of	1,882.30
.3	Hiddon Bridge, surface of water	1,865
.3	High water	1,882
.3	Bridge floor	1,881
.8	Town Branch, mouth of, surface of water	1,862
1.6	25 feet north of bridge, 20 feet west of river, point on bluff rock	1,871.36
	Bridge, surface of water	1,857
	B. F	1,874.8
	High water	1,876
1.7	Hog Creek, mouth of, surface of water	1,855
1.9	Small rapids, surface of water	1,854
2.2	Bell Creek, 900 feet north of, on east edge of river, triple maple tree, nail in side of	1,854.14
2.2	Bell Creek, mouth of, surface of water	1,853
2.3	Small falls, head of, surface of water	1,851
2.3	Small falls, foot of, surface of water	1,847
2.8	Surface of water	1,838
3.4	Sally Ford, mouth of, surface of water	1,836
3.6	Hog Creek, mouth of, surface of water	1,833
3.7	Surface of water	1,830
3.8	Gibson Creek, mouth of, surface of water	1,829
4.8	Long Bullet Creek, mouth of, surface of water	1,825
4.8	Pendelton Ford, 25 feet northwest of, nail in side of dead stump	1,838.20
4.8	Surface of water	1,823

Elevations on Hiwassee River from Hiwassee, Ga., to Apalachia, N. C.—Continued.

Distance in miles.		Elevation in feet.
4.8	High water	1,835
5.2	Sneaking Creek, mouth of, surface of water	1,820
5.5	Surface of water	1,819
5.6	——— Ford, 75 feet northwest of, 10 feet west of road, nail in red-oak tree	1,830.62
6.1	15 feet north of river, point on rock	1,824.63
6.2	Surface of water	1,811
6.4	Stream, mouth of, surface of water	1,809
6.4	Rough Ford, 15 feet north of river, rock bluff, point on rock	1,816.84
6.9	Surface of water	1,807
7.2	Shooting Creek, mouth of, surface of water	1,804
7.9	Barnard Bridge, northeast abutment, point on top of	1,818.31
	Surface of water	1,797
	Bridge floor	1,819.7
	High water	1,814
8.3	——— Ford, surface of water	1,794
8.3	——— Ford, 50 feet south of ford, 15 feet north of river, nail in side of dogwood tree	1,807.89
8.8	Surface of water	1,790
9	Head of island	1,789
9.2	Hyatts Mill Creek, mouth of, surface of water	1,787
9.4	Herbert Ford, on south edge of river at, nail in side of birch tree	1,791.19
	High water	1,799
	Surface of water	1,787
	Blair Creek, mouth of, surface of water	1,787
10	12 feet west of river, point on rock	1,796.74
10	Surface of water	1,782
10.8	Town Creek, mouth of, surface of water	1,778
11.5	Tusquite Bridge, 250 feet west of, on edge of river, nail in root of birch tree	1,778.90
	Bridge, surface of water	1,774
	High water	1,794
11.8	Martin or Quail Creek, mouth of, surface of water	1,174
12.2	Surface of water	1,773
12.6	Tusquitee Creek, mouth of, 150 feet northwest of, 10 feet west of river, nail in root of birch tree	1,777.93
12.6	Surface of water	1,771
12.8	Rapids, surface of water	1,767
13.3	Below rapids, surface of water	1,760
13.6	Stream, mouth of, surface of water	1,759
14	Martin Ford, 125 feet south of, on west edge of river, a fish trap, nail in root of birch tree	1,757.71
	Surface of water	1,756

Elevations on Hiwassee River from Hiwassee, Ga., to Apalachia, N. C.—Continued.

Distance in miles.		Elevation in feet.
14.8	Surface of water	1,742
14.9	Leatherwood Ford, 25 feet northwest of, nail in walnut tree	1,749.19
	Surface of water	1,741
16	Allbon Creek, mouth of, surface of water	1,741
16.4	Surface of water	1,722
17	Fires Creek, mouth of, surface of water	1,712
17.3	Mountain stream, mouth of, surface of water	1,708
17.5	Passmore Ford, east side of river, in center of ford road, nail in root of gum tree	1,709.84
17.5	Surface of water	1,707
17.7	Cloud Fire Creek, mouth of, surface of water	1,700
18.3	Surface of water	1,690
18.8	Betty Creek, mouth of, surface of water	1,685
19.1	Head of island, surface of water	1,679
19.4	Sweetwater Creek, mouth of, surface of water	1,673
19.6	Stream, mouth of, surface of water	1,668
20	Shallow Ford, 15 feet east of river, nail in side of birch tree	1,667.14
20	Surface of water	1,663
20.5	Surface of water	1,659
20.9	End of island, surface of water	1,649
21	Creek, mouth of, surface of water	1,642
21.4	Surface of water	1,632
21.5	Surface of water	1,629
21.8	Backwater of Cherokee dam, 1,500 feet from, at small rapids, surface of water	1,624
22	Top of Cherokee dam, surface of water	1,625
22	Foot of dam, surface of water	1,614
22	Cherokee dam, 25 feet southwest of, point of rock	1,616.59
22	Surface of water	1,609
22.2	Canewater Ford, surface of water	1,606
24	Rocky Branch, mouth of, surface of water	1,591.4
24	North edge of river, nail in side of birch tree	1,594.79
24.1	Small rapids, foot of, surface of water	1,590
24.7	Stream, mouth of, surface of water	1,586
25.2	Brasstown Creek, mouth of, surface of water	1,576
26.2	Island Ford, 700 feet east of, south side of river, point on rock	1,566.56
27.6	Peachtree Creek, mouth of, surface of water	1,550
28	Horseshoe Ford, surface of water	1,549
28	South side of ford, nail in side of beech tree	1,553.06
29.5	20 feet north of river, north side of road, point on rock	1,548.70
29.9	Scott Branch, mouth of, surface of water	1,539
30.4	Stream, mouth of, surface of water	1,529

Elevations on Hiwassee River from Hiwasee, Ga., to Apalachia, N. C.—Continued.

Distance in miles.		Elevation in feet.
31.3	Martin Creek, mouth of, surface of water	1,520
31.6	Twin beech tree, nail in root of	1,518.12
31.8	Stream, mouth of, surface of water	1,513
32.1	Murphy, N.C., iron bridge, south abutment, point on rock	1,518.30
32.1	Surface of water	1,512
32.1	Bridge floor	1,531.9
32.1	High water	1,529
32.5	Valley River, mouth of, west shore, 20 feet north of, in water, point on rock	1,506.85
32.5	Surface of water	1,506
33.6	Surface of water	1,499
34	Surface of water	1,491
34.9	Laurel Creek, mouth of, surface of water	1,474
35.3	Johnson Ford, 8 feet south of river, nail in root of birch tree	1,471.95
35.3	Surface of water	1,469
35.3	High water	1,481
35.9	Hanging Dog Creek, mouth of, surface of water	1,462
36.5	Surface of water	1,459
37	Nottely River, mouth of, surface of water	1,455
37	On land projecting between the two rivers, birch tree, nail in root of	1,459.40
37	Nottely River, mouth of, south side of, willow tree, nail in root of	1,456.93
38	Small rapids, surface of water	1,448
39	Beach Creek, mouth of, surface of water	1,438
40.5	Surface of water	1,425
40.5	Shallow Ford, 40 feet southwest of ford, honey-bee tree, nail in root of	1,431.59
41.2	Surface of water	1,418
42	Grape Creek, mouth of, surface of water	1,416
42.5	Small shoals, head of, surface of water	1,415
42.5	Small shoals, surface of water, foot of	1,410
42.9	Surface of water	1,406
44.1	Persimmon Creek, mouth of, surface of water	1,391
44.8	Foot of large shoals, point on rock	1,390.24
44.8	Surface of water	1,381
45	Head of small shoals, surface of water	1,379
46.2	Dennest Creek, mouth of, surface of water	1,365
46.9	Point on rock	1,363.58
48	Shoals, surface of water	1,346
48.8	Robertson Ferry, 100 feet below, point on rock	1,344.23
48.8	Surface of water	1,343
49.9	Shoals, surface of water	1,340
50.4	Creek, mouth of, surface of water	1,332

Elevations on Hiwassee River from Hiwassee, Ga., to Apalachia, N. C.—Continued.

Distance in miles.		Elevation in feet.
50.6	Surface of water	1,329
51.2	Chambers Creek, mouth of, surface of water	1,324
51.2	20 feet north of bank, point on rock	1,327.94
51.8	Opposite island, surface of water	1,318
52.5	Beaverdam Creek, mouth of, surface of water	1,304
53	Opposite island, surface of water	1,296
53.9	Lared Creek, mouth of, surface of water	1,290
54.3	Shoals, surface of water	1,285
54.3	Foot of shoals, surface of water	1,277
54.8	Surface of water	1,269
55.2	Rapids, surface of water	1,259
56.9	Anderson Creek, mouth of, surface of water	1,248
57.9	Surface of water (15 feet above low water)	1,240
58.5	Shallow Ford, 40 feet south of, nail in root of gum	1,239.67
58.5	Surface of water	1,234
58.5	High water	1,241
58.6	Foot of small shoals, surface of water	1,227
58.9	Shoals Creek, mouth of, surface of water	1,227
59.7	Foot of small rapids, surface of water	1,218
60.8	Stream, south of, surface of water	1,198
61.1	Cane Creek, mouth of, surface of water	1,195
63	Surface of water	1,178
64.2	Camp Creek, mouth of, surface of water	1,175
65	Kilpatrick Ferry, 12 feet south of, willow tree	1,175.14
65	Surface of water	1,172
65.2	Taylor Ferry, 60 feet northwest of, edge of bank, point on large rock	1,169.58
65.2	Surface of water	1,166
66.8	Apalachia, N. C., Sular Creek, mouth of, 100 feet from post-office, 5 feet feet north of bank of river, triple willow tree	1,161.58
66.8	Surface of water	1,158
66.8	High water	1,168

NOTTELY RIVER BELOW BLAIRSVILLE, GA.

Nottely River was surveyed from its mouth, 3½ miles below Murphy, N. C., to Blairsville Bridge, near Blairsville, Ga., a distance of 38 miles. In that distance there is a fall of 314 feet. A line of secondary levels was run, based on a primary bench mark of the United States Geological Survey at Hiwassee, Ga., and the field sheets were plotted on a scale of 1:22,500. During the course of the survey 30 bench marks were established and 88 water-surface elevations obtained.

One mile above the mouth of the river is a 24-foot shoal 1 mile long, where there is an excellent solid rock dam site. At this place a dam would be 200 feet long. Three and one-fourth miles farther up, at Hall Ford, there is a shoal with a fall of 33 feet in 1¾ miles, with good bottom and good sides. A dam would be about 350 feet long.

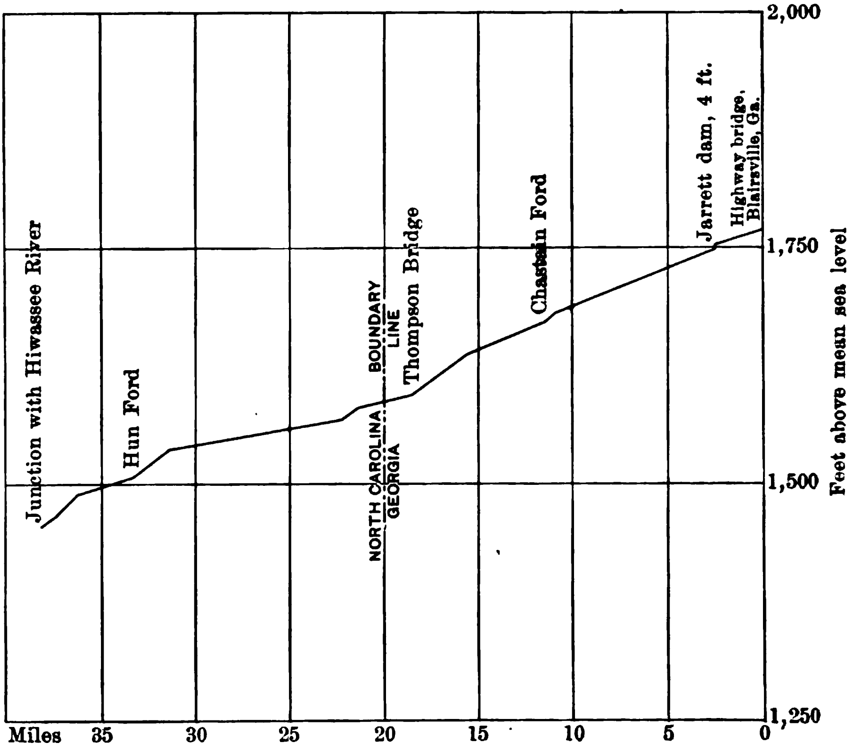


FIG. 15.—Profile of Nottely River below Blairsville, Ga.

For 9 miles above this point the bottoms widen and are cultivated on either side for most of the distance. The fall in this section is a little over 3 feet per mile.

One mile below Laudermilk Ford there is a shoal with a fall of 10 feet in three-fourths of a mile where a dam, with a length of 200 feet, could be built.

At Thompson Bridge, at the foot of a 46-foot shoal, 3 miles long, is an excellent dam site. From Weazel Creek to Morgan Ford, 5½ miles, the river has a fall of 40 feet, and there are two or three suitable sites for small dams. At Watkins Bridge there is a 4-foot dam using all the available power to operate a gristmill.

From here to Blairsville Bridge, the end of the survey, the river is very much smaller, with a few small shoals, which, however, do not seem worth developing.

The elevations in the following list are based upon a bronze tablet marked "1892 Atlanta" in the foundation wall at northwest corner of Union County court-house, Blairsville, Ga., the elevation of which is accepted as 1,891.536 feet above mean sea level. The leveling is adjusted with the Hiwassee River flying levels to accord with the 1903 adjusted elevation of primary bench marks at Blairsville and Hiwassee.

The leveling was done, under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

Elevations on Nottely River from its mouth to Blairsville, Ga.

Distance in miles.		Elevation in feet.
0.0	Junction of Nottely and Hiwassee rivers, on point of peninsular, nail in side of birch tree	1,459.40
.0	Surface of water	1,454.52
.3	At lower ford, surface of water	1,459
.3	Seventy-five feet north of lower ford, nail in root of hickory tree	1,466.77
1	High-water mark	1,471
1	Upper ford, 50 feet south of, nail in root of oak tree	1,474.59
1	Surface of water	1,467
1.3	Surface of water	1,477
1.5	Surface of water	1,472
1.5	Surface of water	1,478
1.8	Deep Ford, 25 feet north of, nail in root of black oak	1,487.56
1.8	Surface of water	1,483
2	Surface of water	1,489
2.3	High water	1,499
2.4	Head of shoals, surface of water	1,491
2.6	Surface of water, rain during night raised 1.3 feet (lower water surface, 1,492.67 feet)	1,493
2.9	Hall Bridge, 20 feet west of, nail in side of apple tree	1,500.20
2.9	Surface of water	1,493
2.9	High water	1,503
4.2	Davis Ford, 20 feet northwest of, nail in side of maple tree	1,504.43
4.2	Surface of water	1,499
4.9	Surface of water, on rock	1,502
5.2	Mouth of Coombs Creek, surface of water	1,505
5.4	Surface of water	1,505
5.5	Hall Ford, north edge of river, nail in side of water birch tree	1,513.02
5.5	Surface of water	1,505
5.5	High water	1,521

Elevations on Nottely River from its mouth to Blairsville, Ga.—Continued.

Distance in miles.		Elevation in feet.
5.9	Mouth of branch, surface of water	1,512
6	Surface of water	1,520
6.6	Surface of water	1,526
6.9	Opposite island, surface of water	1,534
7	Mouth of Rocky Branch, surface of water	1,535
7.1	Near old mill, surface of water	1,538
7.5	Surface of water	1,542
8.6	Nottely Bridge, 1,800 feet north of, in old field near barn, nail in side of persimmon tree	1,559.54
8.6	Mouth of branch, surface of water	1,544
8.9	Nottely Bridge, 100 feet west of, 5 feet south of road, nail in side of black oak tree	1,560.13
8.9	Surface of water	1,544
9.6	Surface of water	1,547
10.5	Mouth of Johnson Branch, surface of water	1,548
10.9	Surface of water	1,551
11.5	Jack Creek, 900 feet south of, in bend of river, 600 feet west and 600 feet north of, in cornfield, nail in root of dead peach tree	1,571.83
11.5	Surface of water	1,554
11.7	Surface of water	1,555
12	Anderson Bridge, 50 feet west of, nail in side of sycamore tree	1,565.78
12	Surface of water	1,556
12	High water	1,575
12.2	Surface of water	1,560
12.9	Mouth of branch, surface of water	1,561
13.3	Ford (has no name), 20 feet northeast of, nail in side of birch stump	1,574.02
13.3	Surface of water	1,562
13.3	High water	1,577
14.2	Surface of water	1,565
15.1	Surface of water	1,568
15.4	Laudermilk Ford, 1.4 miles below, opposite old fish dam, 50 feet west of river, near small branch, nail in root of black oak tree	1,586.77
15.6	Surface of water	1,573
16	Surface of water	1,580
16.8	Laudermilk Ford, 100 feet southwest of, 20 feet north of road, nail in root of apple tree	1,598.19
16.8	Surface of water	1,583
16.8	High water	1,599
17.2	Mouth of Butler Creek, surface of water	1,585
17.7	Below fish dam, surface of water	1,587
17.8	Mouth of Moccasin Creek, surface of water	1,588
17.8	Moccasin Creek, 200 feet south of, 35 feet east of river, east side of road, nail in root of red oak tree	1,602.87

Elevations on Nottely River from its mouth to Blairsville, Ga.—Continued.

Distance in miles.		Elevation in feet.
18.5	Mouth of branch, surface of water	1,591
18.6	Mouth of Dooley Creek, surface of water	1,591
18.9	Thompson Bridge, 250 feet south of, 100 feet southeast of road, nail in root of red-oak tree	1,611.01
18.9	Surface of water	1,592
18.9	High water	1,601.53
19.1	Surface of water	1,599
19.6	In shoals, surface of water	1,611
20.2	Above fish dam, surface of water	1,617
20.4	Head of fish dam, surface of water	1,619
20.8	Foot of island, in shoals, surface of water	1,624
21	Surface of water	1,630
21.4	Chapman Ford, 150 feet north of, 2 feet east of road, nail in root of walnut tree	1,645.81
21.4	Surface of water	1,634
21.4	High water	1,644
21.8	Just below fish dam, surface of water	1,638
21.9	Mouth of Camp Creek, surface of water	1,639
22.6	Above shoals, surface of water	1,652
23	Mouth of Weasel Creek, surface of water	1,655
23.6	Mouth of branch, surface of water	1,656
23.8	In shoals, surface of water	1,657
23.8	Chamber Ford, 0.4 mile northeast of, northwest side of river, point on edge of rock	1,675.88
24.2	Chamber Ford, 200 feet west of, nail in root of walnut tree	1,671.49
24.2	Surface of water	1,661
24.2	High water	1,678
25	Above small shoals, surface of water	1,669
25.2	Chastain Ford, 50 feet west of, nail in side of walnut tree	1,683.45
25.2	Surface of water	1,669
25.5	Foot of large shoals, surface of water	1,675
25.8	Mouth of Ivylog Creek, head of shoals, surface of water	1,680
26.3	Near house, surface of water	1,685
26.6	Majners Ford, 75 feet west of, on edge of bank, nail in side of corn-bean tree	1,690.8
26.6	Surface of water	1,687
26.8	Meadow Ford, 15 feet north of, nail in root of beech tree	1,699.17
26.8	Surface of water	1,689
26.8	High water	1,703
27.3	Huggins Ford, 25 feet north of, corn bean tree, nail in side of	1,707.82
27.3	Surface of water	1,692
27.5	Shoals, surface of water	1,694
27.8	Surface of water	1,698

Elevations on Nottely River from its mouth to Blairsville, Ga.—Continued.

Distance in miles.		Elevation in feet.
27.9	Above shoals, surface of water	1,698
28.4	Morgan Ford, 40 feet north of, red-oak tree	1,714
28.4	Surface of water	1,702
29	Mouth of Young Cane Creek, surface of water	1,699
29	Mouth of Castile Creek, surface of water	1,709
29.1	Castile Creek, 1,600 feet above, on rock, edge of river, point on rock	1,714.20
29.4	Above rapids, surface of water	1,715
30	Above fish dam, surface of water	1,718
30.3	McBee Ford, 60 feet north of, nail in side of red oak	1,734.37
30.3	Surface of water	1,721
30.8	Above branch, surface of water	1,723
31.1	Mouth of Reece Creek, surface of water	1,724
31.4	Youngs Ford, 80 feet southwest of, red-oak tree	1,741.02
31.4	Surface of water	1,727
31.5	Millburn Creek, just below, surface of water	1,730
31.9	At canal, surface of water at foot of	1,732
31.9	Head of canal, surface of water	1,735
31.9	Canal cut, 50 feet northeast of river, 15 feet southwest of ford, nail in root of red-oak tree (cut has a drop of 3.6 feet)	1,741.26
32.2	Above small rapids, surface of water	1,739
33	Mouth of creek, surface of water	1,743
33.6	Watkins Bridge, 375 feet above, north edge of river, point on rock	1,747.54
33.6	Surface of water	1,747
33.6	Jarrett milldam, foot of, surface of water	1,748
33.6	Jarrett milldam, head of, surface of water (Jarrett milldam has a drop of 3.79 feet)	1,752
34.5	Reeds Ford, 150 feet east of, nail in root of walnut tree	1,766.24
34.5	Surface of water	1,755
35	Above small rapids, surface of water	1,760
35.9	Blairsville Bridge, 100 feet southeast of, mouth of Butternut Creek, 15 feet north of, nail in side of red-oak tree	1,775.94
35.9	Surface of water	1,769
35.9	High water	1,783
37.2	Blairsville court-house, Union County, Ga., in wall on west side of building, bronze tablet	1,891.536

TOCCOA RIVER BELOW DIAL, GA.

Toccoa River was surveyed from Butts Bridge, 3 miles east of Dial, Ga., to the Tennessee State line, near McCays, Tenn. In the 36 miles surveyed there is a fall of 414 feet. A line of secondary levels was run, based on the primary bench mark of the United States Geological

Survey, three-fourths of a mile northeast of Butts Bridge. The field sheets were plotted on the scale of 1:22,500, and during the course of this survey 27 bench marks were established and 94 water-surface elevations were obtained.

Toccoa River flows in a northwesterly direction, and after crossing the Tennessee State line is known as Ocoee River. Between Pigeon Creek and Dial Bridge there is a shoal, with a fall of 21 feet in 1¼ miles. There are good foundations for a dam 250 feet long.

From upper Big Creek to Shallow Ford, 3 miles, there is a fall of 55 feet in an almost continuous shoal. There are several available power sites, and building material is easily accessible. From Shallow Ford to Wilscot Creek, 7½ miles, the river has an average fall of 18 feet per mile. There are several excellent sites where there is hard rock on either side.

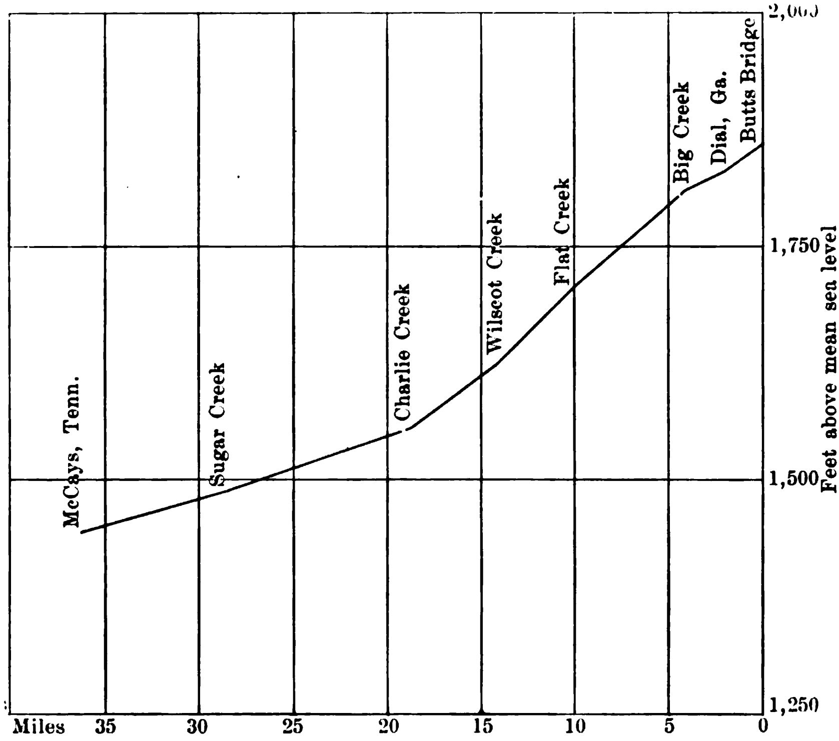


FIG. 16.—Profile of Toccoa River below Dial, Ga.

From Wilscot Creek to Charlie Creek there is an average fall of 14 feet per mile, with several fine shoals having steep hills and good hard bottom.

Eleven miles down the river, at Galloway, Ga., there is a shoal with a fall of 10 feet in half a mile. This would be a good site for a small dam. From one-half mile below Galloway to McCays, Tenn., 6 miles, the river has a fall of 60 feet, with several good power sites.

The elevations in the following list are based upon an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta, marked "1050 M C," the elevation of which is now accepted as 1,049.546 feet above mean sea level. They accord with the 1903 adjusted elevations of primary bench marks near Morganton and Shallow Ford. The section from Shallow Ford to McCays Ferry is a single spur line.

The leveling was done under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

Elevations on Toccoa River from Butts Bridge, Georgia, to Tennessee State line.

Distance in miles.		Elevation in feet.
0.0	Morganton (3 miles east of Dial), forks of Morganton and Ellijay road, in large marble rock, copper bolt marked "1981"	1,947.821
1.5	Butts Bridge, surface of water	1,858
1.5	Butts Bridge, east side of, nail in top of abutment	1,874.25
1.5	High-water mark	1,870
2	Pigeon Creek, 550 feet east of, north side of road, 60 feet north of river, point on rock	1,858.35
2	Mouth of Pigeon Creek, surface of water	1,849
2.3	Between rapids, surface of water	1,845
2.5	Foot of shoals, surface of water	1,840
2.9	Mouth of Weeks Creek, foot of rapids, surface of water	1,830
3.1	Dial post-office, Van Zant's bridge, 100 feet north of, east side of road, nail in root of red-oak tree	1,844.68
3.1	Surface of water	1,828
3.1	High-water mark	1,851
4	Mouth of Noontootly Creek, surface of water	1,823
4	Mouth of branch, surface of water	1,821
4.2	Rogers Ford, 50 feet west of, nail in root of tree	1,825.14
4.2	Surface of water	1,820
4.7	Surface of water	1,815
5.1	In rapids, surface of water	1,813
5.2	Big Creek Ford, 225 feet southeast of, 50 feet south of river, nail in root of white-oak tree	1,817.74
5.2	Surface of water	1,810
5.2	In rapids, surface of water	1,809
5.7	Above rapids, surface of water	1,802
5.9	Below fish dam, surface of water	1,799
6.1	Head of shoals, surface of water	1,795
6.4	Foot of shoals, surface of water	1,791
6.4	Surface of water	1,790
7	Surface of water	1,782
7.1	Shallow Ford, 1 mile north of, north side of road, in large rock, copper bolt marked "1859"	1,826.439

Elevations on Toccoa River from Butts Bridge, Georgia, to Tennessee State line—Continued.

Distance in miles.		Elevation in feet.
	Single flying level spur line to McCays Ferry.	
7.1	Below rapids, surface of water	1,779
7.6	In rapids, surface of water	1,769
8.1	Shallow Ford, 100 feet north of, nail in root of red-oak tree	1,774.93
8.1	Surface of water	1,763
8.1	High-water mark	1,774
8.3	In rapids, surface of water	1,758
8.6	Surface of water	1,755
8.8	Mouth of Stanley Creek, surface of water	1,752
9.1	Rapids, surface of water	1,747
9.3	Mouth of stream, surface of water	1,743
9.5	Below rapids, surface of water	1,738
9.9	Stanley Creek, 1 mile northwest of, opposite island, north side of river, point on rock	1,738.77
10	In rapids, surface of water	1,729
10.2	Opposite falls in river, 50 feet north of first falls, point on large rock	1,744.02
10.2	Head of falls, surface of water	1,728
10.2	Foot of falls, surface of water	1,719
10.7	Mouth of branch, surface of water	1,717
11	Below rapids, surface of water	1,709
11.2	Mouth of Flat Creek, surface of water	1,705
11.5	In rapids, surface of water	1,691
11.6	Surface of water	1,690
11.8	Head of long shoals, surface of water	1,689
11.8	Rock cliff, south side of river, opposite large shoals, point in side of	1,692.11
11.9	Head of island, in shoals, surface of water	1,679
12	Foot of island, in shoals, surface of water	1,677
12.9	In shoals, surface of water	1,665
13.3	Foot of large shoals, surface of water	1,659
13.4	Below rapids, head of more shoals, surface of water	1,656
13.4	In rapids, surface of water	1,646
14	Foot of shoals, surface of water	1,640
14.6	Mouth of Persimmon Creek, surface of water	1,633
14.6	Persimmon Creek, 300 feet east of, west side of river, nail in root of large dead stump	1,638.06
14.7	Below fish dam, surface of water	1,629
15.2	Mouth of stream, surface of water	1,624
15.4	Mouth of Wilscot Creek, surface of water	1,624
15.8	In shoals, surface of water	1,616
16	Foot of shoals, surface of water	1,609
16.8	In rapids, surface of water	1,602

Elevations on Toccoa River from Butts Bridge, Georgia, to Tennessee State line—Continued.

Distance in miles.		Elevation in feet.
	Single flying level spur line to McCays Ferry—Continued.	
8	Wilscot Creek, 1.5 miles northwest of, rock cliff, 18 feet north of river, point on very large rock	1,608.96
16.9	In shoals, surface of water	1,600
17.1	Foot of shoals, surface of water	1,596
17.3	Tarpley Ford, surface of water	1,593
17.3	Tarpley Ford, 20 feet west of, nail in root of beech tree	1,598.30
17.6	In rapids, surface of water	1,589
18.2	Mouth of creek, surface of water	1,576
18.3	Surface of water	1,571
18.8	Mouth of creek, surface of water	1,568
19	Mouth of Bullfrog Creek, surface of water	1,565
19.6	Surface of water	1,559
20	Mouth of Charlie Creek, surface of water	1,555
20	Lovingood Ford, 300 feet northeast of, nail in side of walnut tree	1,564.61
20	Surface of water	1,554
20	High-water mark	1,569
21.5	Mouth of Star Creek, surface of water	1,550
21.6	Below fish dam, surface of water	1,548
22	Mouth of Rogers Branch, surface of water	1,547
22.4	Toccoa Bridge, surface of water	1,546
22.4	Toccoa Bridge, 10 feet east of, nail in root of beech tree	1,557.64
22.9	Mouth of spring stream, surface of water	1,540
23.5	Below small rapids, surface of water	1,539
23.6	Mouth of Weavers Creek, surface of water	1,538
23.9	At Benchlog Ford, surface of water	1,538
23.9	Benchlog Ford, 20 feet northeast of, nail in side of beech tree	1,543.47
25.2	Large bend in river, surface of water	1,528
25.5	Atlanta, Knoxville and Northern Railroad bridge, east side of bridge abutment, point on rock	1,536.79
25.5	Surface of water	1,526
25.5	High-water mark	1,541
26.6	Mouth of branch, surface of water	1,519
26.8	Harts Ford, 100 feet west of, stump on edge of bank at canoe landing, nail in side of	1,521.90
26.8	Surface of water	1,516
28	Surface of water	1,510
28.8	Bakers Ford, 100 feet southeast of, on edge of bank, nail in side of birch tree	1,515
28.8	Surface of water	1,507
29.6	Surface of water	1,504
30	Bend of river, surface of water	1,502

Elevations on Toccoa River from Butts Bridge, Georgia, to Tennessee State line—Continued.

Distance in miles.		Elevation in feet.
	Single flying level spur line to McCays Ferry—Continued.	
30.2	Surface of water	1,498
30.9	Mouth of Sugar Creek, surface of water	1,494
30.9	Sugar Creek railroad bridge abutment, point in center of east side of bridge	1,508.32
31.2	Below Galloway Ford, surface of water	1,592
31.5	In shoals, surface of water	1,589
32.1	200 feet northwest of ford, 4 feet southeast of Atlanta, Knoxville and Northern Railroad track, nail in side of peach tree	1,562.69
32.1	Surface of water	1,484
32.5	Canoe Landing, surface of water	1,479
32.8	Hothouse Creek, mouth of, surface of water	1,476
33.7	Foot of small shoals, near island, surface of water	1,467
34	Mouth of Barker Creek, surface of water	1,464
34.5	Kyle post-office, 600 feet east of, Atlanta, Knoxville and Northern Railroad bridge over Barker Creek, on southeast end of, end bolt	1,482.43
34.6	Kyle post-office, 40 feet south of, in front of Queen Brothers' store, pile supporting platform, nail in top of	1,483.62
34.6	Kyle ford, surface of water	1,463
35	Below rapids, surface of water	1,458
35.4	Mouth of Wolf Creek, surface of water	1,455
35.8	Atlanta, Knoxville and Northern Railroad bridge over Ocoee River, east side of bridge, point on abutment	1,471.98
35.8	Surface of water	1,452
36.1	In bend of river, surface of water	1,450
36.3	Dillbeck Ford, north edge of river, nail in side of dead birch tree	1,451.87
36.3	Surface of water	1,447
37.5	McCays post-office, Polk County, Tenn., rock supporting southwest corner of, point on	1,468.07
37.5	McCays Ferry, north side of river, pile supporting swinging bridge, cartridge shell in top of	1,460.15
37.5	High-water mark	1,469
37.5	Surface of water	1,444

CHIPPEWA RIVER FROM REEDS LANDING, MINNESOTA, TO FLAMBEAU, WIS.

Between April 15 and June 12, 1903, J. R. Ellis, field assistant, ran a careful double-rodded primary-level line along the Chippewa River from Reeds Landing, Minnesota, to Chippewa Falls, Wis. This work was under the general direction of J. H. Renshawe, geographer in charge of the central section of topography. Later in the year it was decided to continue this work above Chippewa Falls, and on

September 1 the central and eastern sections having united as the eastern section of topography, H. M. Wilson, geographer in charge, assigned F. T. Fitch, field assistant, to this work. Between that date and October 4 Mr. Fitch ran a line of flying levels accompanied by a plane-table stadia traverse and topographic sketching from Chippewa Falls to Flambeau, Wis.

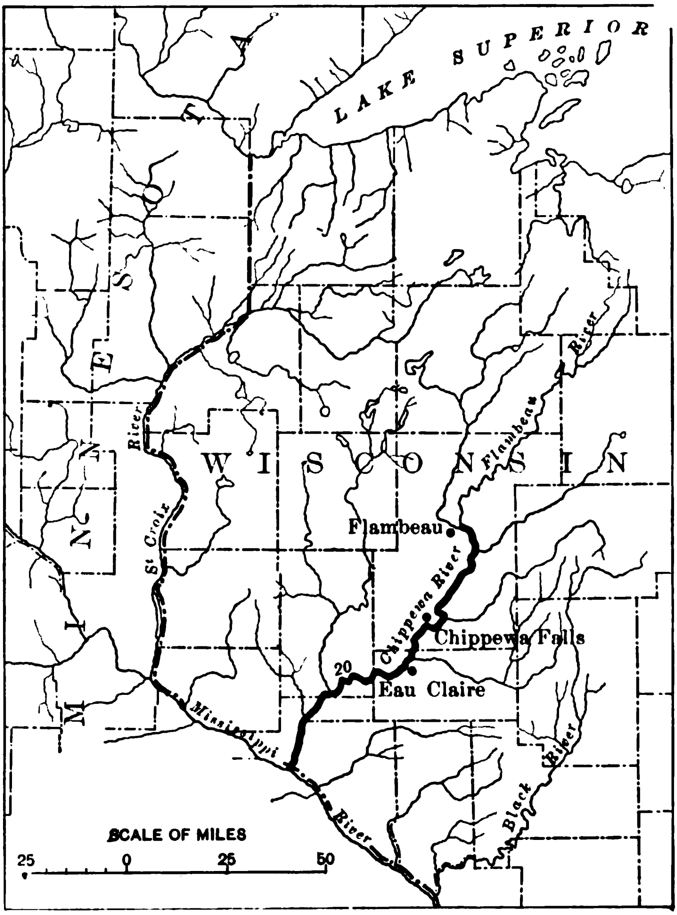


FIG. 17.—Map showing location of surveys in Wisconsin.

This level work is based on a bench mark of the Mississippi River Commission at Reeds Landing, and the distances were obtained by pacing. No plane-table survey of the river was undertaken. In this section, 64 miles in length, there is a fall of 135 feet. Eleven bench-mark tablets and 70 temporary bench marks were established, and 72 water-surface elevations were determined.

While the survey was being made the stage of the river fluctuated greatly, owing to rains and to alternate flooding and stoppage of the stream by various lumber companies. This diversion of the water is the cause of much complaint by the various mill owners, many of whom want a system of reservoirs constructed near the headwaters to regulate the water supply.

Owing to the slight fall, the width of the stream, and the wide bottom lands, there are no opportunities for power development upon the Chippewa above Reeds Landing until the city of Eau Claire is reached.

On Eau Claire River, a few hundred feet above its junction with the Chippewa at Eau Claire, is a 13-foot dam 300 feet long, which furnishes power for a linen mill. A few miles above the city of Eau Claire on Chippewa River the Dells Paper Company has a 20-foot dam which might be raised 3 or 4 feet by the use of flashboards. There are no power sites on Chippewa River until the city of Chippewa Falls is reached, but there are good prospects of developing power on several of the tributaries between these cities.

From Chippewa Falls to Flambeau the stadia survey of the river and adjacent banks was plotted on a scale of 1:22,500. In this distance, 43 miles, there is a total fall of 244 feet. Seven bench marks were established and 40 water-surface elevations were determined.

At Chippewa Falls a wooden 13-foot dam, owned by the Chippewa Falls Lumber and Boom Company, increases the head to 30 feet and supplies power for a large sawmill, and an electric plant which furnishes the city of Chippewa Falls with water and light. This dam could be made higher, as the local conditions are favorable, but this would interfere with a proposed plant at Paint Creek Rapids, 2½ miles upstream, to which point the water now backs up. Here there was formerly a flooding dam, but a freshet cut a channel around it to the north, and the dam has since been torn out. A 14-foot dam could be constructed at the foot of the rapids where the banks and bed of the river are sand intermingled with large bowlders. Abundant stone for construction is near at hand.

At Eagle Rapids, 4½ miles upstream, is a good site for a dam. A dam here was torn out. A 20-foot dam would back water three-fourths of a mile above the city of Chippewa, where O'Neils Creek enters from the west. One mile above O'Neils Creek is a gorge 700 feet wide. A 25-foot dam would have solid sandstone for foundation and abutments and would back water almost to the foot of Jim Falls, 5 miles above. At the small village of Jim Falls, near the site of an old flooding dam, is the best opportunity for power development on the river. This point is now under development, the company having purchased all the land needed as well as the water rights. The river flows over a series of granite ledges from 1 to 4 feet high, while the banks seem to be solid rock covered by a few feet of sandy soil. The proposed dam will be 28 feet high and will be located at the head of the rapids. It will furnish power for a pulp mill. The dam will back water nearly to Brunne Falls, 9½ miles, and covers the Colton and Chevalley rapids. The head obtained by this dam will be 55 feet.

At Brunne Falls the best location for a dam would be at the main fall, about 650 feet above the foot of the rapids, where a 35-foot dam would back the water up to the rapids at Holcombe, 5½ miles. The river at the falls is very narrow, and at the point mentioned the banks are ledges of rock. A rocky island in the river would help in the construction a good deal.

At Holcombe the Chippewa Falls Lumber and Boom Company has an old dam with a head of about 17 feet. This is the third dam they have built there, the others having been washed out by freshets. As the lumber interests in this locality are declining, the present dam is being allowed to decay, and could be replaced with a more substantial structure for power purposes. The river here has a rock bottom and rather low, clay sides, and an 18-foot dam could be constructed on the site of the present structure, which, together with a 15-foot dam at the foot of the rapids, would not destroy any more valuable bottom lands above. This would back the water up for more than a mile above Deer Tail Creek and furnish considerable storage. From here to Flambeau, the end of the survey, there are no rapids of any consequence.

There are two railway bridges and a highway bridge across the river at Chippewa Falls and another road bridge just below Eagle Rapids. There are but few boats on the river, as during the log-driving season boats would be crushed.

The lumbering operations, which are on the decline, are controlled by the Chippewa Falls Lumber and Boom Company, with headquarters at Chippewa Falls, a thriving city of about 10,000 population, where there are a number of factories and mills. About ten miles above is the city of Chippewa, at one time the most promising town in the neighborhood, but now little more than a hamlet. At Jim Falls there is a village, but Holcombe is the only town of any importance above Chippewa Falls. Several railroad lines are being built in this section, and the agricultural and manufacturing interests are supplanting the lumber industry, while the land is generally taken up by settlers wherever the lumber has been cut, so that no second-growth timber is coming up. The whole community seems very prosperous, while numerous companies are on the point of investing capital in the manufacturing interests in the neighborhood.

The elevations of water surfaces of the river are dependent on the following table of daily gage readings by the Chippewa Falls

Lumber and Boom Company from a gage on the highway bridge at Chippewa Falls. The elevation of the zero of gage is 804.8 feet above sea level. The gage height of the highest water known had an elevation of 831.4 feet above sea level.

Gage height of Chippewa River at Chippewa Falls.

Date.	Height.		Date.	Height.	
	Ft.	*In.*		*Ft.*	*In.*
May 1	8	10	June 6	3	10
2	8	6	7	2	2
3	8	0	8	2	6
4	8	0	9	3	0
5	7	9	10	2	9
6	7	3	11	2	6
7	6	8	12	2	6
8	5	6	13	2	2
9	5	6	14		
10			15	1	6
11	5	6	16	1	6
12	8	9	17	1	6
13	9	6	18	1	3
14	9	6	19	0	6
15	9	1	20	2	6
16	8	1	21		
17			22	1	0
18	6	3	23	1	3
19	5	8	24	1	0
20	5	2	25	0	9
21	5	3	26	0	9
22	5	8	27	0	9
23	5	3	28		
24			29	1	6
25	5	9	30	1	10
26	6	4	July 1	3	8
27	8	8	2	4	10
28	11	0	3	5	7
29	12	5	4	9	6
30	11	8	5	10	6
31	10	3	6	10	3
June 1	8	8	7	9	0
2	7	10	8	7	9
3	6	6	9	6	9
4	5	9	10	5	1
5	4	9	11	6	0

Gage height of Chippewa River at Chippewa Falls—Continued.

Date.	Height.		Date.	Height.	
	Ft.	*In.*		*Ft.*	*In.*
July 12	6	0	Aug. 22	1	9
13	5	4	23		
14	4	6	24	1	9
15	4	3	25	1	9
16	3	3	26	1	9
17	3	3	27	1	9
18	5	0	28	2	0
19	1	0	29	2	3
20	2	10	30	2	6
21	2	6	31	2	3
22	2	3	Sept. 1	2	3
23	2	3	2	2	9
24	2	3	3	2	3
25	3	0	4	2	0
26			5		
27	2	6	6	2	3
28	1	9	7	2	6
29	1	6	8	2	8
30	1	4	9	4	0
31	1	0	10	4	4
Aug. 1	1	3	11	5	1
2	1	6	12	7	0
3	2	0	13	7	8
4	2	9	14	9	6
5	3	6	15	12	4
6	5	3	16	13	3
7	5	3	17	12	6
8	6	9	18	11	0
9	3	6	19	9	6
10	3	10	20	8	6
11	3	8	21	7	3
12	3	0	22	6	4
13	3	3	23	5	6
14	3	2	24	4	6
15	3	6	25	3	3
16			26	3	3
17	3	0	27	3	3
18	2	6	28	3	4
19	2	0	29	3	3
20	1	6	30	3	3
21	1	6	Oct. 1	3	3

Gage height of Chippewa River at Chippewa Falls—Continued.

Date.	Height.		Date.	Height.	
	Ft.	*In.*		*Ft.*	*In.*
Oct. 2	3	3	Oct. 5	7	10
3	3	6	6	8	1
4	5	9	7	8	0

The elevations in the following list are based upon a bronze tablet, marked "797 E. C," at southwest corner of the court-house at Eau Claire, Wis., the elevation of which is accepted as 797.473 feet above mean sea level. The initial point upon which these levels depend is bench mark "Bottom," of the Missouri River Commission, opposite Reeds Landing, Minnesota, the elevation of which is accepted as 672.355 feet above mean sea level. These elevations accord with the 1903 adjustment of the precise-level net.

Permanent bench marks dependent on this datum are marked with the letters "E. C." in addition to the figures of elevation.

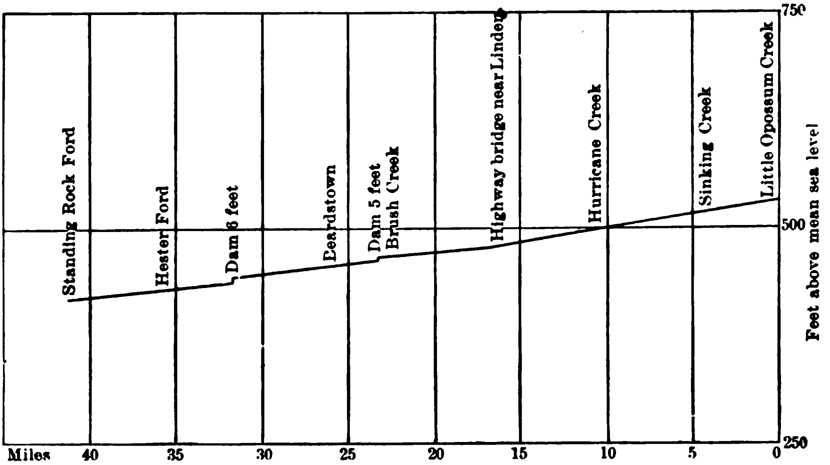


FIG. 18. Profile of Chippewa River from Reeds Landing, Minnesota, to Flambeau, Wis.

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.

Distance in miles.		Elevation in feet.
0.0	Reeds Landing, Minnesota (Miss. River Commission bench mark "Bottom"), tile and iron pipe in low flat ground, opposite, 220 meters from left bank of river, in property of Mrs. C. S. Richards, 45 meters west of Chicago, Milwaukee and St. Paul Railroad trestle to bridge, 205 meters southwest of end of trestle and small pond..	672.355

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
0.5	High water in back water of slough	672
1.4	Trevin's, at grade crossing Burlington and Chicago, Milwaukee and St. Paul railroads, top of rail	684.3
1.4	15 feet northwest of intersection of grade crossing, spike in telegraph pole	684.89
1.9	15 feet northwest of end of trestle, nail in top of fence post	680.01
2.6	Lone narrow island, lower end of, left bank of river, birch tree, nail in root of	677.46
2.6	High water	674
3.2	Private road crossing, top of rail	681.4
3.5	Government dam, 300 feet below, opposite north end of small island, left bank of river, water maple, nail on notch	680.36
3.5	High water	675
3.6	300 feet north of rapids, high water	676
3.8	Wancuda Island, 0.25 mile below north end of, left bank of river, notch cut on elm tree, nail in	681.52
4.3	North end of Government dam, 100 feet below, left channel, surface of water	677
4.5	165 feet east of river, water maple tree, notch cut in	681.13
4.5	Surface of water	678
0	Near north corner of C. W. Knight's yard, in top of limestone 8 by 10 by 26 inches, set 25 inches in ground, bronze tablet marked "682 E. C."	682.337
5.5	Opposite trestle 32 H, surface of water	680
5.8	Old Battle Slough station, in west side of switch stand, spike	685.28
6.2	Surface of water (river about 1 foot above ordinary stage)	681
6.6	Bridge No. 38 M, 50 feet south of, west side of dump, cross on stone	685.28
6.7	Bridge No. 42 M, private road crossing south of, top of rail	688.41
7.4	Bridge No. 50 M, at south end of, east side of track, nail in cross cut in cap	688.26
7.4	Surface of water	683
7.9	Private crossing, top of rail	692.1
7.9	Surface of water	685
8	Second telegraph pole north of slough, spike in	689.33
8.5	Elm tree on left bank of river, nail in notch cut in	689.36
8.5	Surface of water (1.9 feet higher than stage observed nearer mouth)	687
9	Trestle No. 60 M, top of rail	....
9	Surface of water	688
9.6	Maxwell station, surface of water	691
9.6	Maxwell, 180 feet southwest of platform, in sandstone post 8 by 12 by 80 inches, set 27 inches in ground, bronze tablet marked "691 E. C."	691.196
10.3	Trestle No. 66 M, Little Belf Slough, surface of water	691

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
10.6	West side of railroad, near gate at private road crossing, nail in top of stump	694.91
10.6	Surface of water (is about 4 feet lower than low water)	693
11.4	South end of trestle No. 70 M, 15 feet east of railroad, cross on sandstone	701.32
11.9	Big Beef Slough, 150 feet below railroad bridge No. 74 M (is about 3 feet above low water) surface of water	695
12.3	595 feet north of bridge, on west side of track, nail in top of post	711.65
12.4	Private road crossing, top of east rail	714.61
12.8	Pawn's farm, private road crossing, top of west rail	724.3
13.4	T. 24 N., R. 13 W., just outside of Chicago, Milwaukee and St. Paul Railroad right of way, left bank of river, and 0.25 mile due west of center sec. 6, in sandstone post 12 by 6 by 30 inches, bronze tablet marked "733 E. C."	732.878
13.4	Surface of water	698
14	Round Hill, 0.25 mile below, left bank of river, black oak tree, nail in notch cut in	737.7
14	Surface of water	699
14.4	Road in front of barn	733
14.4	Surface of water	699
14.6	Round Hill, north and south road crossing on Chicago, Milwaukee and St. Paul Railroad	731.4
15.2	Road crossing on east side of railroad, spike in signboard	740.56
15.9	Private road crossing, top of rail	724.55
16.1	Durand, 100 feet north of south switch block, 12 feet east of center of track, north end of sandstone, cross	717.54
16.5	300 feet north of brewery, east and west road crossing, top of rail	720.6
16.8	Durand, road crossing north of station, top of rail	724.7
16.8	Durand County jail building, water table at southwest corner of, bronze tablet marked "724 E. C."	724.361
16.8	Upper bridge, surface of water	703
17.5	Durand, north part of, at north end of siding, 35 feet northwest of switch block, cottonwood tree, notch cut in root, nail in	727.23
	Spur line up river.	
18.2	Elm tree, left bank of river, nail in notch	707.24
18.2	Surface of water	705
18.5	Creek from east, white oak tree at, nail in notch on root	707.20
18.5	Creek, at mouth, surface of water (river is about 2 feet above low water)	706
	Main line continued.	
18.8	Northwest corner of trestle No. 96 M, nail in top of fence post	717.24
18.8	Surface of water	711
19.1	Beaver Creek, surface of water	712

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
19.1	Trestle No. 98 M, top of sandstone, at southeast end of trestle	714.55
19.7	Trestle No. 100 M, southeast corner of, spike in cap	715.60
19.7	Surface of water	713
20.4	Bear Lake, 0.75 mile north of, private road crossing, top of west rail.	733.2
20.6	Private road crossing, top of east rail	735.1
21.1	Whistle post for road crossing, spike in	735.62
21.2	East and west road crossing, top of west rail	735.8
21.4	Northwest and southeast road crossing, top of west rail	737.2
22.1	Weber's house, road crossing, top of rail	745.8
22.1	Crossing post, near bottom, railroad spike	746.52
22.4	Trestle No. 106 M, section line between secs. ——— top of rail	749.64
22.8	Red Cedar, 0.33 mile south of, T. 25 N., R. 12 W., sec. 6, one-quarter corner north side of, in ground at T road east, sandstone 6 by 12 by 30 inches, bronze tablet marked "755 E. C."	755.670
23.1	Red Cedar, west part of, foundation to water tank	758.36
23.1	Red Cedar, road crossing, top of rail	758.9
23.3	Surface of water	721
23.9	Private road crossing, top of rail	735.2
24	Private road crossing, spike in base of first telegraph pole north of	731.37
24.2	Red Cedar Junction, at switch block, top of east rail	729.3
24.4	Red Cedar Junction, surface of water at bridge	721
24.6	Trestle No. 108 M, at southwest corner, nail in top of fence post	730.45
24.6	Surface of water	722
25.7	Tyrone (abandoned station), 750 feet south of, spike in telegraph pole	727.97
25.7	Surface of water	724
25.8	Tyrone, at road crossing, top of rail	732
26.4	Private road crossing, top of rail	731.2
26.7	Trestle No. 116, fence post at southwest corner of, nail in top of	732.96
26.7	Surface of water	724
26.9	Private road crossing, top of west rail	733.24
27.1	Railroad spike in crossing post	731.5
27.4	Road crossing (second one north of public crossing), top of rail	732.9
27.9	Trestle No. 118 M, at southeast corner of, in top of fence post	733.04
27.9	Surface of water	728
28.8	Meridian, T. 26 N., R. 12 W., sec. 14, north part of, at southeast corner of Iver Brock's residence, in stone foundation, bronze tablet marked "740 E. C."	739.923
28.8	Road crossing, top of rail	739.2
29.4	Private road crossing, top of rail	739.8
29.6	Trestle No. 124 M, at east end of, nail in top of fence post	738.46

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
29.6	Surface of water	733
29.7	North and south road crossing, top of rail	739.6
30.1	North and south road crossing, cross on stone	740.30
30.1	Road crossing, top of north rail	741.7
31	Road crossing, spike in telegraph pole	745.02
31	Wagon bridge, surface of water	739
32.2	South side of railroad, 60 feet west of large spring, cross cut in sandstone	751.82
32.2	Surface of water	741
33	Spike in base of telegraph pole	747.85
33.7	Opposite small island, on highest point of large sandstone bowlder, cross cut	753.19
33.7	Surface of water	743
34.1	On bank of river at right of way fence, sandstone bowlder, cross cut in top of	754.70
34.5	Rock Creek, surface of water	744
34.7	Private road crossing, top of rail	752.9
34.9	Trestle No. 144, at northwest corner of, nail in cross cut in cap	751.22
35.8	Caryville, T. 26 N., R. 11 W., sec. 11, east part of, at northwest corner of post-office, Strand's general store, in stone foundation, bronze tablet marked "760 E. C."	760.144
35.9	Road crossing, top of rail	757.7
	[Line continued along highway.]	
36.3	Wagon bridge over West Creek, in top of pile at east approach, nail	753.98
36.3	Surface of water	746
37	East of small island, water maple 40 feet east of river, on left bank, nail in root of	749.63
37	Surface of water	747
38.3	Powell Lake and Chippewa River roads, 75 feet east of junction, small double elm tree, nail in root of	756.15
39.1	Surface of water	752
39.5	Surface of water	752
40.7	On left bank of river, at east end of long log boom, nail in maple stump	763.11
40.7	Surface of water	755
41.3	Coolies Lake, near outlet, B. A. Churchville residence, at southwest corner of, in foundation, bronze tablet marked "779 E. C."	779.356
41.4	Surface of water	758
42.4	Porterville, 0.75 mile south of, wagon road culvert, nail in top of pile	763.92
42.4	Surface of water	761
43	Old Porter mills, nail in root of large water maple	764.84
43.3	T roads	767

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
43.3	Creek, mouth of, surface of water	764
43.8	On river bank, 30 feet west of road, nail in top of stump	767.85
44.1	Surface of water	764
44.8	Charles Bannon's residence, 120 feet southeast of, at gate, nail in white oak stump	771.08
44.9	Lower Creek, road crossing on Chicago, Milwaukee and St. Paul Railroad, top of rail	773.4
44.9	Surface of water (higher than has been for 2 years)	768
45.5	Shawtown, 1 mile south of, T. 27 N., R. 10 W., sec. 36, northeast corner of, in stone foundation at northwest corner of Henry Trimble's residence, bronze tablet marked "781 E. C."	780.84
45.5	High water, in 1884	777
45.8	Road crossing	776.5
45.8	Surface of water	769
46.5	Shawtown, 200 feet south of railroad bridge, spike in base of telegraph pole	783.98
46.5	Under bridge, surface of water	769
46.6	Menomonie street crossing, top of rail	777.6
47.6	Eau Claire, crossing of Niagara and Seventh street	781.2
48.1	East entrance to high school, first window to right, in sill, cut in center	797.93
48.3	Eau Claire, at southwest corner of court-house, bronze tablet marked "797 E. C."	797.473
48.4	Crossing of Grand and Oxford avenue, top of rail	791
48.7	200 feet south of railroad bridge, spike in base of crossing post	787.33
48.8	Center of railroad bridge over river	788.3
48.8	Eau Claire River, mouth of, surface of water under bridge (June 2)	770
	[Spur line, June 9, up Eau Claire River from junction. Stage of water 6.5 lower.]	
.1	Junction of Chippewa and Eau Claire rivers, June 9, foot of first dam at mouth of, on Eau Claire river	763.5
.1	Head of same dam	774
.75	Foot of second dam	774
.75	Head of second dam	786.8
	[Main line continued June 2. River is 6.5 feet higher than a week later.]	
49	Eau Claire court-house, 0.7 mile north of, at Chicago, Milwaukee and St. Paul Railroad station, top of rail	786.05
49.1	Forrest street crossing of spur to paper mill, top of rail	778.6
49.4	Elm street crossing, top of rail	780.3
49.4	The Dallas Paper Mill Company dam, foot of, surface of water	772
49.4	The Dallas Paper Mill Company dam, head of, surface of water	793
49.8	Chicago and Northwestern Railroad bridge over river, south corner of east pier, cross cut on	804.36

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
50.6	Chicago and Northwestern, at mile post St. Paul 87, top of rail	843.1
50.7	Duluth Branch, at overhead road crossing, top of rail	851.8
50.8	Duluth branch, Chicago and Northwestern Railroad, on east side of railroad, opposite yard-limit post, spike in base of telegraph pole.	858.56
51	Road crossing, top of rail	871.3
51.4	Mile post 1, top of east rail	882.8
51.6	Power house at crossing of Chicago, Milwaukee and St. Paul and Chicago and Northwestern railroads, 1,100 feet south of, spike in telegraph pole	882.09
51.9	Grade crossing, top of rail	881.2
52	Chicago, Milwaukee and St. Paul and Chicago and Northwestern railroads, grade crossing, top of rail	880.2
52.6	Road crossing, top of west rail	843.5
52.6	20 feet west of north cattle guard to road crossing, in base of fence corner post, spike	840.09
53.2	Road crossing, top of rail	813.8
53.3	Second pole west of road crossing, spike in	807.97
53.5	Dalles Mill station, road crossing, top of west rail	804.2
54.4	Road crossing on line between Eau Claire and Chippewa counties	813
54.4	County line crossing, in north cattle guard, nail in top of fence post	815.18
54.8	East and west road crossing, top of east rail	821.1
54.8	Surface of water	793
56.1	La Fayette, road crossing at old site of, top of west rail	817.4
56.1	Surface of water	794
56.1	La Fayette, second telegraph pole above road crossing at old site of, spike in	818.75
57.3	North and south private road crossing, spike in black oak tree	815.96
.0	Surface of water	794
57.4	Road crossing east and west	821.9
58.3	Badger Mills, road crossing just below north switch block	817
58.3	Halle Lake, Badger Mills, surface of water	815
58.4	Badger Mills, just south of waiting shed, spike in crossing post	818.19
58.4	Badger Mills, opposite waiting shed, top of east rail	820.2
58.76	Badger Mills, summer hotel, in ground in lawn of, 50 feet due west of front window, sandstone post 10 by 8 by 30 inches, bronze tablet marked "827 E. C."	827.716
59.4	150 feet west of P. C. mark, 150 feet south of gate, spike in base of telegraph pole	831.45
59.4	Surface of water	797.3
60.5	Surface of water	801
60.6	Trestle No. 216, in sleeper at west end of, painted cross on bolt	833.51
61.1	Gravel Island, crossing post just below, spike in base of	855.19
61.1	Gravel Island, slough, mouth of, surface of water	803

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
62.1	Surface of water	805
62.2	Spike in base of crossing post	840.31
62.2	Road crossing, top of rail	842.4
62.8	Central Junction, Chicago, Milwaukee and St. Paul Railroad and Wisconsin Central Railroad, switch block at	832.4
62.9	East side of railroad, spike in base of telegraph pole	832.9
62.9	Road crossing, top of rail	833.9
63	Center of Chicago, Milwaukee and St. Paul Railroad bridge, top of rail	834.03
63	Surface of water under bridge	805
63.3	Junction of Chicago, Milwaukee and St. Paul Railroad and Wisconsin Central Railroad (main line), top of rail	840.3
63.8	Chippewa Falls, 20 feet south of water tank, spike in base of telegraph pole	830.63
63.9	Chippewa Falls, Taylor street crossing, top of rail	833.7
63.9	Chippewa Falls, under bridge, foot of dam, surface of water	807
64.31	Chippewa Falls, northeast corner of city building containing fire department and city jail, in foundation, bronze tablet marked "840 E. C."	840.468
64.4	Chippewa Falls, above dam, surface of water	840
	[Flying levels by F. T. Fitch, field assistant, Chippewa Falls, up Chippewa River to Flambeau.]	
.0	Highest water mark on record, recorded by Chippewa Falls Lumber and Boom Company, Sept. 10, 1884	832
.0	Second highest water mark of Chippewa River, recorded Dec. 3, 1896	831
.0	Lowest water mark of Chippewa River, reading taken at Chippewa Falls	804
.0	Highway bridge at falls, surface of water	806
.0	Chippewa Falls, surface of water	826
.0	Crest of dam of Chippewa Falls Lumber Company, surface of water	839
3.7	Paint Creek Rapids, foot of, north bank of river, 50 feet from water, top of bowlder, chiseled square	844.54
5.5	Yellow River, mouth of, surface of water	852
8	Eagle Rapids, foot of, surface of water	854
9.2	Eagle Rapids, head of, surface of water	867
10.7	Surface of water	871
13	Foot of rapids, surface of water	881
15.7	Jim Falls, east side of river at edge of water, nearly opposite Pitch Hotel, at foot of rapids, in granite ledge, chiseled square	902
15.7	Surface of water	901
16.6	Head of rapids, surface of water	936
17.9	Coltons Rapids, foot of, surface of water	942.2
19.2	Coltons Rapids, head of, surface of water	945

Elevations on Chippewa River, from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
19.2	Chas. Richards, near house occupied by, 150 feet south of road intersection, at edge of water, rock, chiseled square	947.40
20.2	Shaw Creek, 400 feet above mouth of, surface of water	....
22.9	Bob Creek, mouth of, surface of water	954
25.7	Chevalley Rapids, foot of, surface of water	961
26.9	Above rapids, surface of water	966
26.9	Brunne Falls, at boat landing, west bank of river, below main falls and just above Chevalley Rapids, 125 feet south of old house, 50 feet from water, bowlder 2 feet square, chiseled square	984.19
27	Brunne Rapids, foot of, surface of water	967
28	Brunne Rapids, head of, surface of water	993
29.5	Fisher River, mouth of, surface of water	995
32.7	Holcombe, foot of rapids, surface of water	1,004
33.2	Holcombe, foot of dam, surface of water	1,020
33.2	Above dam, surface of water	1,036
33.2	South entrance to bridge over flooding dam, 500 feet west of, south side of highway, 50 feet south of river, on bowlder in fence, chiseled square	1,046.55
39.7	Deer Tail Creek, mouth of, surface of water	1,036
43.3	Flambeau, post-office, at intersection of Flambeau and Chippewa rivers, on point of land, nail in root of tree	1,055.09
43.3	Junction of rivers, surface of water	1,050

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

WATER PROBLEMS

OF

SANTA BARBARA, CALIFORNIA

BY

J. B. LIPPINCOTT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Hydrographic Branch,
Washington, D. C., May 12, 1904.

Sir: I have the honor to submit herewith, for publication as a water-supply and irrigation paper, a report on the water problems of Santa Barbara, Cal., transmitted by Mr. J. B. Lippincott.

As the city and suburbs of Santa Barbara form one of the most attractive and productive districts in southern California, a thorough knowledge of the water supply of the region is of the utmost importance. It is thought that the facts brought out in the report will be of much interest.

Very respectfully,

F. H. Newell,
Chief Engineer.

Hon. Charles D. Walcott,
Director United States Geological Survey.

WATER PROBLEMS OF SANTA BARBARA, CAL.

By J. B. LIPPINCOTT.

INTRODUCTION.

The Santa Barbara coast extending from Goleta to Carpinteria, including the city and suburbs of Santa Barbara, is naturally one of the most attractive and productive districts of southern California. It is, however, deficient in water supply.

Desiring a broad and comprehensive study made of this locality, with a view to a solution of the problems involved, the city and county of Santa Barbara have requested (1) that the topographic work of the Geological Survey be extended so as to cover this district, and (2) that the hydrographic branch of the Survey make an investigation of the water problems involved. These topographic surveys have now been made, and the maps of the Goleta, Santa Barbara, Santa Ynez, and Mount Pinos quadrangles have been published. The Santa Maria quadrangle has been surveyed and the map is now being engraved. This will complete the mapping of the county. These topographic maps are of the very greatest assistance and importance in determining relative elevations, areas and elevations of drainage basins, and possible tunnel locations through the Santa Ynez Range.

In the hydrographic investigations the city of Santa Barbara has cooperated, paying one-half of the expense connected with the maintenance of a gaging station on Santa Ynez River and Mono Creek, on which streams daily observations have been made for silt, volume of flow, and mineral impurities of the water, and also approximately 25 per cent of the expense connected with the preparation of this report. This portion of the work, therefore, is in the nature of a joint investigation by the city of Santa Barbara and the Geological Survey, all of the field work and investigation being done by the Survey and a portion of the expense being paid by the city of Santa Barbara.

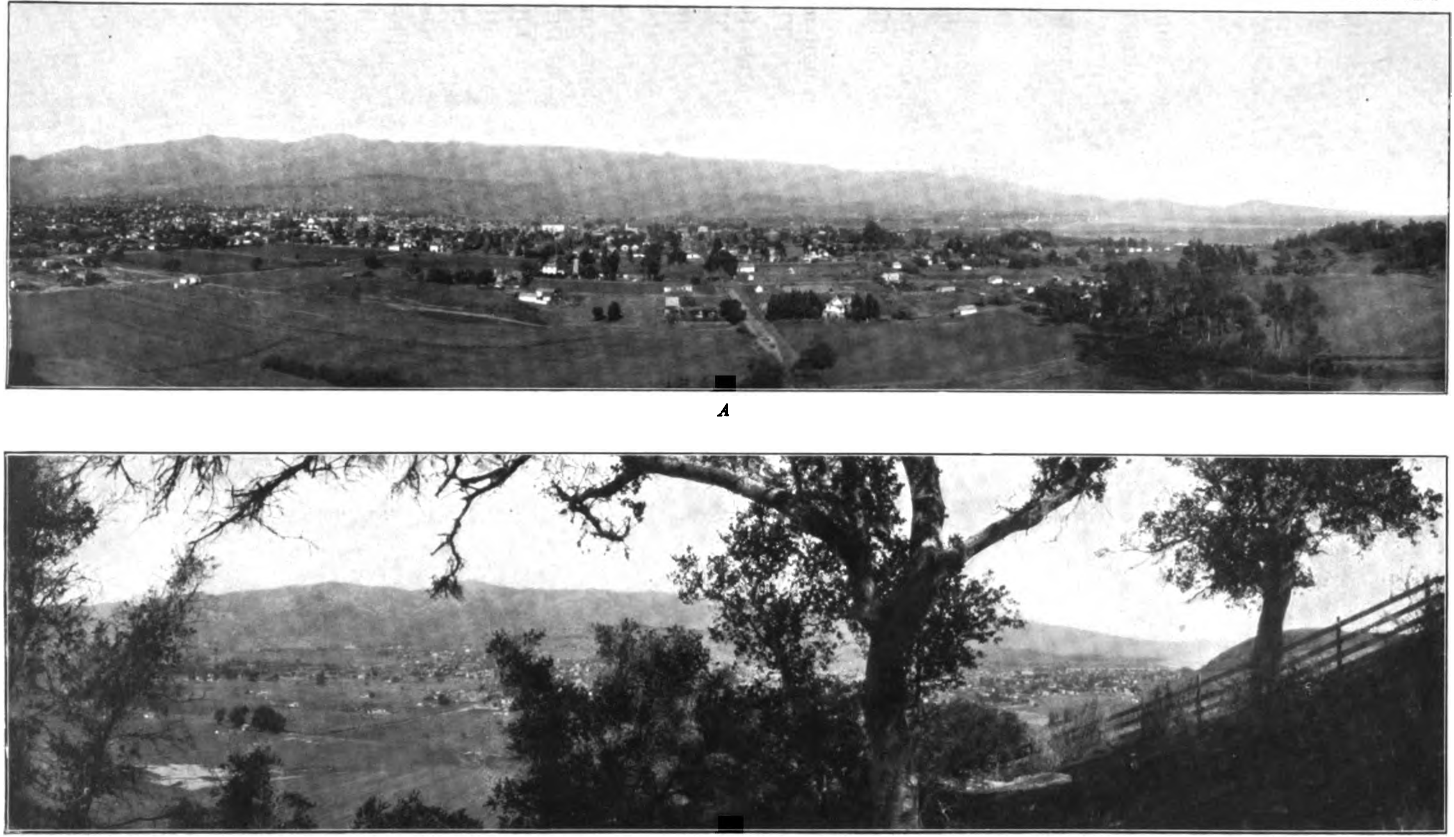
LOCATION AND DRAINAGE OF THE DISTRICT.

The district under investigation extends from Ventura River in Ventura County along the coast as far as Goleta in Santa Barbara County, and more particularly into the high mountainous districts of Ventura and Santa Barbara counties lying on the north side of the Santa Ynez Range and including the drainage basin of Santa Ynez River and its tributaries.

The coastal plain fronting the ocean consists of a series of old marine beaches and undulating foothills facing Santa Barbara Channel. Views of this coastal plain are shown in Pl. II. This district is of great natural beauty, and has become the home not only of agriculturists and horticulturists, but also of many eastern people who have sought it for recreation and health. It is one of the most attractive regions in California. The winds are mild, those from the south being tempered by the Pacific Ocean, and those from the north being barred out by the Santa Ynez Range, which parallels the coast, rising to elevations of from 3,000 to 4,000 feet and presenting a bold and attractive background to the undulating foothill districts. (See Pl. I.)

The streams flowing from the southern slope of this range are precipitous and have short drainage basins of small area. This topography produces a torrential stream condition after rains, followed by a period of extreme low water in time of drought. The range is formed chiefly of shale and sandstone, the strike being parallel to the coast and the dip nearly vertical, inclining somewhat to the south. This geologic formation admits of a number of small but permanent springs in the canyons eroded by the streams, and is also favorable to the development of water by tunnels run at right angles to the line of strike. Beyond the crests of the Santa Ynez Range is the drainage basin of Santa Ynez River. A second range of mountains, consisting of the crest of the Coast Range and culminating in Mount Pinos, the elevation of which is 8,826 feet, rises to the north and trends parallel to the Santa Ynez Mountains. These higher mountains are drained by streams running in a southerly direction and uniting with Santa Ynez River proper, which runs close to the northerly base of the Santa Ynez Mountains, flowing westerly and paralleling the Coast Range. It has a total length of about 70 miles, with flat grades, and offers frequent opportunities for impounding water in storage reservoirs.

The results of the investigations indicate that a solution of the water problem for the coast district lies in impounding the flood waters in the drainage basin of Santa Ynez River and conveying them to Santa Barbara through a long tunnel beneath the Santa Ynez Range.



A

B

VIEWS OF SANTA BARBARA AND VICINITY.

REVIEW OF EARLIER WORK BY OTHERS.

It is here deemed proper to review the work which has been done along this line in the past by other engineers, both for the city of Santa Barbara and for the Santa Barbara Water Company. The first report was made for the city of Santa Barbara on October 19, 1889, by George F. Wright, member American Society of Civil Engineers, and at the time city engineer of Santa Barbara. The second report was presented on July 2, 1896, by Ernest J. S. Purslow, civil engineer for the Santa Barbara Water Company. Both of these gentlemen, who are now deceased, were residents of Santa Barbara, engineers of distinction, men of good standing in the community, and thoroughly acquainted with local conditions. In general their judgment respecting the subject here under consideration is approved by the present writer, both from personal knowledge of the locality and from observations elsewhere. Their opinions particularly with reference to local water supplies on the south side of the range are worthy of acceptance, and it was not deemed necessary or advisable to make further field examinations over this ground which they had previously covered in detail. Because these reports were made a long time ago and are now unfamiliar to many new residents, and are out of print, it is considered advisable to briefly review them.

REPORT OF GEORGE F. WRIGHT, 1889.

NEEDS OF DISTRICT.

Mr. Wright states: "I have endeavored to cover the whole field in my report, trusting in many cases to previous examinations and surveys made by myself, aided by the available maps of that portion of the territory lying south of the summit of the Coast or Santa Ynez Range of mountains." He calls attention to the fact that even at that time the city had never had an ample water supply to meet its demands, a condition which, as all the residents of the district are well aware, has never been materially changed. He states further: "The immediate necessity demands a supply of 2 million gallons per day (equivalent to 200 gallons per capita for 10,000 persons), which will certainly be increased to 3 million gallons, and probably 4 million gallons, per day before many years." This statement was made on the assumption that the city, with an ample water supply, would have a vigorous growth, and a development proportional to that of other towns of southern California as suitably located and having adequate supplies. In marked contrast with this demand, he states that the low-water flow of Mission Creek (a present source of supply) is reported to fall as low as 300,000 gallons daily in midsummer, and that a trial test of the De la Guerra wells showed an average daily output of 600,000 gallons at that time.

STREAMS SOUTH OF COAST RANGE.

A complete investigation was made by Wright of all the adjoining drainage basins, extending from Rincon Canyon on the east to Cañada Refugio on the west, during the summer of 1889. The rainfall at Santa Barbara had been 21.44 inches during the preceding winter, and 21.71 inches the winter before that—unusually good records, as the Santa Barbara mean is only 16.78 inches. Consequently Mr. Wright's figures on stream flow are above what should be accepted as an average condition. His table descriptive of the streams is given below.[a]

TABLE 1.—*Streams east of Santa Barbara and south of Coast Range.*

Name of stream.	Catchment area in square miles.	Distance from city in miles.	Daily flow in miner's inches (1889).[b]	Remarks: Flow in miner's inches.
Rincon, proper	8.8	17	5.8	June 16, 1900: 1.5.
Gobernador	7.8	16	29.0	
Carpinteria, including Sutton	5.3	15	3.9	June 16, 1900: 0.1.
Santa Monica	3.6	11	11.6	
Parida, including Oil	3.3	10	15.5	
Ficay	1.4	8	15.5	
Dinsmore	3.0	6	11.6	July 18, 1902: 3.0.
Cold Spring	3.8	4	11.6	
Mission, including Rattlesnake	5.7	1	23.2	June 14, 1900: 1.0. June 17, 1900: 2.5.
Total daily summer flow	....	....	127.7	

---

[a] During the last year the United States Geological Survey has made a detailed topographic field survey of the mountainous district in the vicinity of Santa Barbara, indicating in contours the area of drainage basins, together with their altitude. These maps are more accurate than any previous ones, and have been used in determining the drainage areas of all the streams described by Wright that could be recognized from his names. In each case the area has been determined above the point where the stream issues from the foothills or mountains. In the case of a few of these streams other measurements are available for later years. These are included and show, particularly for the year 1900, a marked decrease in volume over that measured by Wright. The rainfall in the year 1899–1900 at Santa Barbara was 12.68 inches.

[b] A miner's inch is taken as equal to one-fiftieth of a cubic foot per second, or a flow of 12,925 gallons per day.

TABLE 2.—*Streams west of Santa Barbara and south of Coast Range.*

Stream.	Catchment in square miles.	Length in catchment.	Distance from city in miles.	Daily flow in miner's inches.	Remarks: Flow in miner's inches.
Arroyo Burro		2.5	2.5	11.6	June 17, 1900: 1.5.
Maria Ygnacia	5.7	2.0	6.0	[a] 11.6	
San Jose	6.0	2.5	7.0	13.6	July 30, 1900: 38.1.
San Pedro	2.7	2.0	9.5	3.9	
Arroyo Carnero	3.3	2.0	10.0	3.9	
Annes	4.0	1.0	12.0	3.9	
Annito		1.5	13.0	1.9	
Tecolote	5.2	2.5	14.0	13.6	
Aguila	4.5	2.0	15.0	5.8	
Dos Pueblos	6.7	2.0	17.0	27.2	
Cañada Verde (Las Varas)	2.5	2.0	18.0	3.9	
Cañada Llaces	1.5	2.0	20.0	3.9	
El Capitan	1.5	1.0	22.0	11.6	
Cañada del Corral	1.0	1.0	23.0	7.7	
Cañada Refugio	2.0	2.0	25.0	15.4	
Total				139.5	

[a] Laguna Blanca Water Company.

Wright correctly states that the grades of these local streams on the south side of the mountains are very steep, affording no opportunities for the construction of storage reservoirs. He also states that while it might be possible to divert some of these storm waters by means of large canals into basins in the flat lands to the side, the work would be exceedingly expensive and impracticable.

The conclusion that he reaches with reference to the streams on the south side of the Coast Range is as follows:

> I do not deem it practicable to secure an ample supply of water for Santa Barbara south of the Santa Ynez Range of mountains, for the following reasons:
>
> 1. The aggregate daily summer flow of the entire watershed from Rincon Creek to and including Refugio Creek is less than 4 million gallons per day.
>
> 2. This flow is all claimed by riparian owners, water companies, and individual water claims.
>
> 3. Storage-reservoir sites of sufficient capacity and elevation do not exist along the streams, if at all. The construction of numerous small reservoirs would increase the operating expenses and also the first cost of construction.
>
> 4. Diverting dams in the streams would be necessary to turn the winter flow, and the conduits leading to the storage reservoirs would necessarily be large and expensive.
>
> 5. It is very doubtful if the city of Santa Barbara could establish a claim on the waters of these streams which would enable her to obtain them through legal process. Where it is possible to do so, however, the city can not afford to appropriate water which, if not now needed, soon will be, for the supply of the rapidly increasing population of the Carpinteria and Montecito valleys on the east and the Goleta and Dos Pueblos on the west.

STREAMS NORTH OF COAST RANGE.

Having failed to find an adequate supply of water on the south side of the range, the investigations of Wright were extended to the north side of the range, into the basin of Santa Ynez River. Surveys to determine relative elevations were made, and detailed reports on two reservoir sites, one known as the Juncal, near the head of the Santa Ynez, and the other as the Main River reservoir site, below the mouth of Blue Canyon. A general view of the basin of Santa Ynez River is shown in Pl. III, *B*.

From a study of the rainfall data available at the time of his report Wright concludes that it will be necessary to have a storage reservoir capable of holding water from years of average or excessive rainfall for years of deficient rainfall. He believes that in some winters there will be little, if any, storm water in these streams. From April, 1876, to October, 1877, inclusive, there was a period of drought of nineteen months in which the rainfall was insufficient to much more than supply evaporation. On his basis of 200 gallons per day per capita, for a population of 20,000, requiring 4 million gallons per day, this would call for a storage of 2,280 million gallons, which is equal to 7,000 acre-feet of water, an acre-foot being the volume of water sufficient to cover 1 acre 1 foot deep, or 43,560 cubic feet.

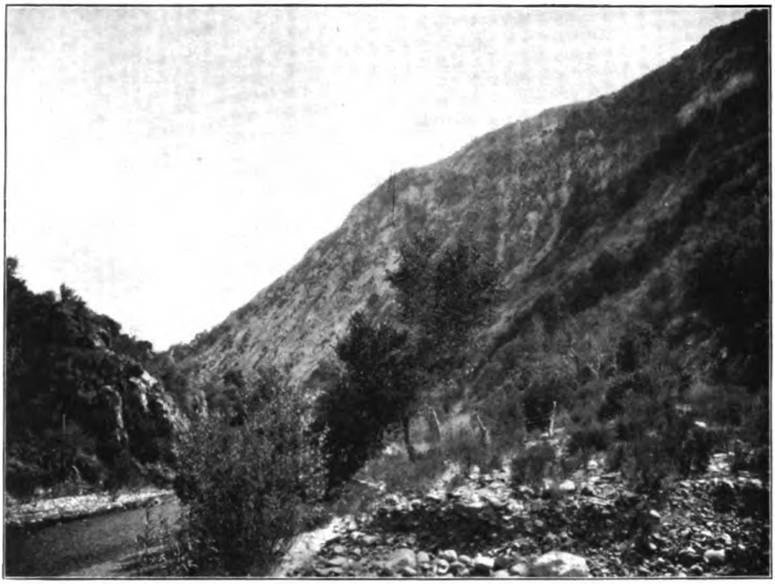
JUNCAL RESERVOIR SITE.

The Juncal reservoir site was determined to have the following capacities with the heights of dam stated:

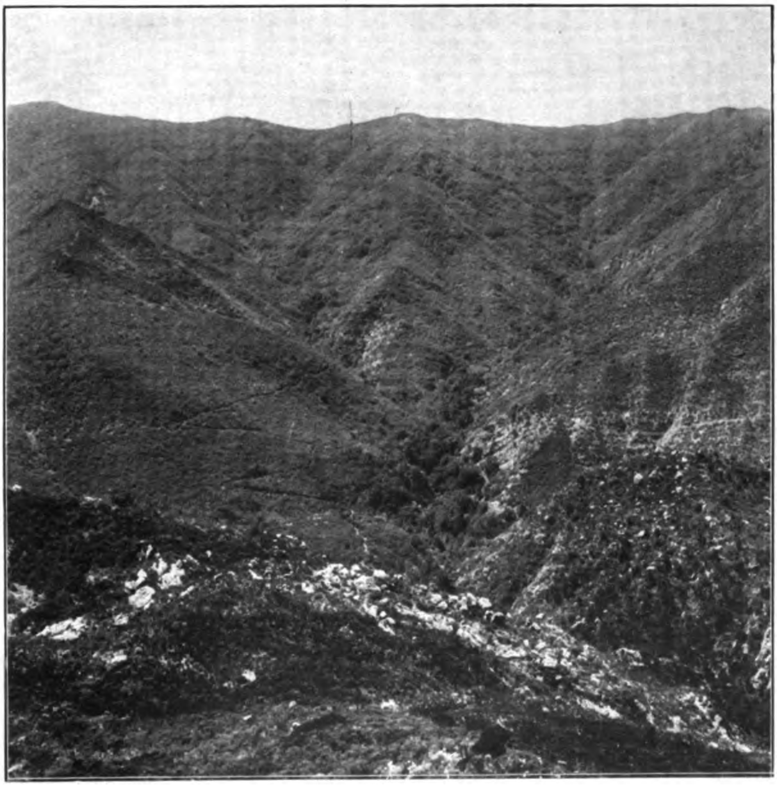
TABLE 3.—*Capacities of Juncal reservoir with various heights of dam.*

Height of dam in feet.	Capacity in gallons.	Capacity in acre-feet.
200	4,000,000,000	12,276
175	2,352,000,000	7,218
150	1,877,000,000	5,760
125	1,437,000,000	4,410
100	1,050,000,000	3,222
75	705,000,000	2,164
50	350,000,000	1,074

A dam 200 feet high would be 550 feet long on top, and one 100 feet high would be 272 feet long on top. Purslow in his report estimates that a dam at the Juncal 100 feet high, with a diversion conduit to Santa Barbara, would cost $300,000. The area of the drainage basin is given as 23.5 square miles by both Wright and Purslow. From the topographic surveys of the United States



A. MONO CREEK DAM SITE AND GAGING STATION.



B. SANTA YNEZ BASIN ON PROJECTED LOCATION OF OLD CITY TUNNEL.

Geological Survey it is found that they were seriously in error, and that there is but 13.4 square miles of area naturally tributary to this reservoir site. This directly affects the value of the Juncal as a storage reservoir. Wright gives certain figures showing that, in his judgment, the water supply would be always sufficient to meet the demands upon this reservoir. At the time the reports of both Wright and Purslow were written little available data existed indicating the flow that might be expected from drainage basins on the Pacific coast, particularly in southern California. Estimates were therefore based upon observations on eastern streams. Since that time, however, the United States Geological Survey has been measuring California streams and determining drainage areas and their rainfall, and there is now better information available on this subject. The whole trend of these late stream measurements has been to show that estimates of run-off for southern California, particularly those based on observations on eastern rivers which were previously considered as comparable, give excessive and unreliable results. While it is impossible to predict accurately what the discharge from any given drainage basin will be, nevertheless, from examinations made of the basin of the Santa Ynez and the application of average conditions observed in localities somewhat

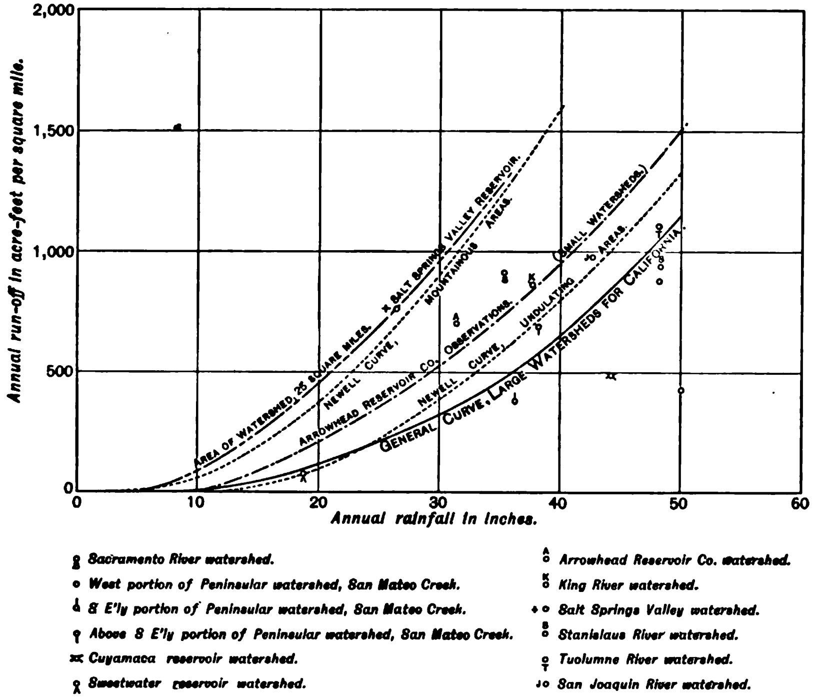


FIG. 1.—Diagram showing relation of rainfall to run-off for California streams. (For description see page 50.)

similar and of a mountainous character, it is possible to form an approximately correct idea of the true results. Table 12 shows the estimated run-off from the drainage basin of the Juncal and neighboring streams in detail. From an extended comparison of rainfall data it is believed by the writer that the precipitation on average years in the basin of the Santa Ynez may possibly reach 22 inches. But since late records indicate less rainfall, the Santa Barbara mean of 16.78 is used by the author as the basis of his estimates in table 12 (p. 53). Wright considers that it will be over 20 inches throughout the drainage basin, and Purslow that it will be 27 inches. The rainfall in the mountains varies in the same ratio for wet and dry years as the rainfall at Santa Barbara city. The first rains are absorbed by the ground and retained in the soil until evaporated either from the surface or by the growing plants. It takes about 9 inches of rain to meet these demands, and, generally speaking, no material stream flow will result from a winter's rain unless it exceeds this amount, provided all of this precipitation does not occur in hard successive storms, in which event there would be run-off; usually, however, there will be no stream flow unless the winter rain exceeds 9 inches. When these demands of evaporation are met, the succeeding storms furnish more and more of a water supply for the streams, and the per cent of rain so discharged increases in a growing ratio.

From the studies above referred to, assuming a rainfall of 25 inches in this basin, it is concluded that during the year 1897–98, when the rainfall at Santa Barbara amounted to 4.99 inches, there would have been no high-water stream flow in the mountains. In 1898–99 there would have been available at the Juncal reservoir 1,114 acre-feet; in 1899–1900, 1,367 acre-feet. This is a three-year mean of 827 acre-feet, which would yield a supply of but 730,000 gallons per day, evaporation not being deducted. These figures, compared with Wright's estimated necessary supply of 4,422 acre-feet annually to meet future conditions reasonably within sight (20,000 people), show that the Juncal reservoir site and drainage basin would be inadequate to meet the demands of the city of Santa Barbara. The conclusion of Wright or of Purslow that the Juncal alone is a suitable source for a water supply for the city can not be accepted, although it may be used properly as a supplemental reservoir for hold-over purposes, its waters being liberated at such periods as may be necessary to make up for deficiencies in reservoir sites lower on the stream. In conclusion Mr. Wright makes the following statement:

> I consider the Santa Ynez River above the mouth of Blue Canyon to be not only an available source of supply, but the only source possible for the future supply of Santa Barbara with an abundance of good potable water, for the following reasons:

1. Not only the sources of the streams but the entire river are uncontaminated by any of the organic wastes pertaining to civilization, and from the rugged nature of the country are likely to remain so. The sandstone gathering-grounds are of the best class for delivering water free from mineral impurities.

2. The elevation and capacity of the storage sites and the extent of the catchment insure an ample supply of water in all seasons.

3. The riparian rights in that portion of the stream sought to be appropriated are merely nominal, as none of the summer flow above Blue Canyon ever appears on the surface as far down as the San Marcos rancho. The only riparian owner is therefore the owner of the Los Prietos y Najalayegua rancho.[a] This right can probably be purchased, or if not, can be condemned by legal process.

4. The expansive capacity of the district for increasing the supply to meet all possible demands is ample and in excess. This feature alone, other things being equal, should decide in favor of this source of supply.

5. Storage reservoir sites are numerous and ample. The fall of the stream being comparatively light, renders it practicable to arrest the entire flow to the extent required by the demand.

6. The expense of constructing a thoroughly efficient and permanent system of works is no greater than would be the cost of works of equal capacity on the coast side, and maintenance will be much less.

I also recommend the construction of the works as a whole. Omitting the storage reservoir is simply gambling on our good luck, viz, that we will not have a dry season this year or next, and so on until we do get a dry year, when it will be too late to save ourselves from great discomfort and possible pecuniary loss.

REPORT OF E. J. S. PURSLOW, 1896.

Mr. Ernest J. S. Purslow, deceased, a civil engineer, living in Santa Barbara at the time and employed by the Santa Barbara Water Company, investigated in 1896 the same questions covered by Wright's report of 1889. As engineer for the water company, he would naturally have a point of view somewhat different from that of the representative of the city.

Purslow states that the present Santa Barbara Water Company, which consolidated the water rights on Mission Canyon and the De la Guerra wells, was incorporated in January, 1889. This was done in order to increase the available water supply then obtained from Mission Creek by a gravity system of diversion, and from the De la Guerra wells, located in the city limits, by a pumping system.

NEEDS OF DISTRICT.

Purslow says:

The present water supply is so inadequate and incomplete that it is a physical impossibility for the city to increase in size or population, or for the surrounding country to advance in development, until water is procured from a source other than those in the immediate vicinity, which are now all used to their fullest capacity. The scarcity of water is the first impression that visitors receive, and many who have desired to make this their home have abandoned the idea owing to the gravity of this drawback.

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[a] On December 22, 1903, this ranch was included in the Santa Barbara Forest Reserve, lien scrip having been issued to the owners for it.

By the general introduction of meters and the most economical type of service taps the supply of 130 gallons should be ample for all purposes; at which rate the immediate demand of the present population would be about 1 million gallons per diem. The total supply at present, during the dry months of a year with average rainfall, is about 600,000 gallons per diem, about half from the Mission streams and half from the De la Guerra wells.

Nothing has retarded the advance of the city so much as the condition of the water supply, and nothing will promote its future prosperity and growth as much as a remedy for this condition. The present demands of the city being upwards of 1 million gallons per diem, a system could not be considered adequate which will not have a capacity to supply at least 1,500,000 gallons per diem as soon as work can be constructed, with means for subsequently increasing the supply with the growth of the city.

The suburbs of Santa Barbara, and the land extending easterly and westerly from the city, are improved only to the extent to which the waters of the small mountain streams have been made available, principally at points adjacent to and riparian on these streams. West of the city, where small quantities of water are obtained, the land is devoted principally to horticulture, and where water is not obtainable it is used as grazing and farming land. East of the city lies the famed district of El Montecito, which is inhabited, to the extent to which the small streams can supply water, by a class of people who for the most part have independent means, many of whom have built substantial and handsome houses and beautified their grounds, and among whom there are enough people of intellectual pursuits and tastes to form a nucleus which makes it especially attractive for that class of people. It is primarily and distinctively a residence district. Consisting of a gentle slope from the foothills toward the channel, broken and diversified by the natural watercourses, which, though bereft of water during the summer months, are lined with natural timber growth, backed and protected on the north by the Santa Ynez Mountains, nearly every spot commanding a comprehensive and magnificent view of the channel and coast line and the distant islands, possessing the most equable climate in the world and everything else which Almighty God could give except plenty of water, it is destined to become one of the garden spots of the world.

Land which has water is sold at from $500 to $1,000 an acre, and although land has very little productive value without water, such dry land is held and readily sold in El Montecito district at from $250 to $500 an acre. In spite of the unprecedented business depression of the past two years, sales of this land have been made during this period of some 40 tracts scattered through this district, aggregating some 670 acres, at an average price of about $330 an acre. There is no other residence district in California where prices for bare, dry, suburban or agricultural land have been so maintained and sales so extensively made during the past two years. El Montecito comprises about 4,500 acres of land susceptible of irrigation, only a small fraction of which is supplied with water for more than domestic purposes. The duty of water here for full-bearing lemon orchards has been found to be one miner's inch to 10 acres of land with the average soil, a miner's inch being equivalent to a continuous flow of 12,960 gallons per diem. Many lemon orchards have been planted during the past two years on tracts of land which have appurtenant to them such small allowances of water that it is feared that the trees will die before reaching full maturity. When orchard trees are young and small a very small quantity of water suffices to moisten the soil immediately surrounding them; but, as they increase in size and their roots extend, it is necessary to use water enough to irrigate the whole orchard surface. The owners of such orchards will be compelled to purchase more water or see their years of labor end in failure. Ornamental grounds, vegetables, oranges, and other fruits require about the same quantity of water as lemons.[a]

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[a] The tunnel line from the lower reservoir sites on the Santa Ynez (see p. 41) will command all the lands of El Montecito as well as of the city of Santa Barbara. The elevation of the south portal of the present city tunnel is 1,393 feet above sea level. The new tunnel line proposed through Mission Canyon will be at an elevation of 1,186.46 feet (Geological Survey datum).

POSSIBLE SUPPLY.

Purslow then proceeds to show that the proper and adequate solution of the water problem for Santa Barbara and vicinity consists of the storage of the storm waters of Santa Ynez River and their diversion by means of tunnel lines to the south side of the range. He states that there are three available sites for storage reservoirs on lands owned by the water company on the Santa Ynez—one in Blue Canyon, which he afterwards condemns as an impracticable proposition because of its expense and small drainage area; one on the main river near the confluence of the Blue Canyon with the Santa Ynez, which he names the Main River reservoir site, and which has a large storage capacity; and a third, the Juncal reservoir site, near the headwaters of the stream.

BLUE CANYON SITE.

He states that the Blue Canyon site is located at an elevation of 1,500 feet above sea level, with a drainage area of only about 8 square miles. A contour survey which he made showed that a dam 100 feet high above the bed of the gorge would impound 1,500 million gallons, equivalent to 4,600 acre-feet. He admits that the local drainage naturally tributary is totally inadequate to fill this reservoir. It would require a tunnel 10,550 feet long to connect this reservoir with the south side of the mountains.

MAIN RIVER SITE.

In describing the Main River reservoir site he said: "This is one of the best in California"; certainly a very singular statement for an engineer to make, in view of the fact that the width of the dam site on the bed of the creek is 427 feet. He says the drainage area tributary to the Main River reservoir site is 150 square miles, ranging in elevation from 1,500 to 6,000 feet, with a mean rainfall of 30 inches in the drainage basins and a probable minimum of 7 inches. From the recent official surveys of the United States Geological Survey it has been definitely determined that the drainage area above this reservoir site is 71 square miles. The elevation of the bed of the canyon at the Main River dam site is 1,460 feet above sea level. This reservoir site is of such elevation as to command by gravity the present city tunnel line, which may be extended as the outlet for the Mono reservoir site (see pp. 40–41). The Main River reservoir site is owned by the Santa Barbara Water Company and is of some merit. If a tunnel is carried through the range this reservoir, commanding the present city tunnel in elevation, may ultimately be built, either by the water company or by its successors, thus materially adding to the supply for the district south of the mountains, which demands all the water possible to be obtained from Santa Ynez River.

JUNCAL SITE.

Purslow states that an observer was stationed at the Juncal, recording the rainfall and taking measurements of the flow of the stream during the " past winter," and that these records show that up to the date of writing the flow available for storage was upwards of 800 million gallons (2,455 acre-feet). This quantity includes the flow of Alder Creek basin (2.4 square miles), which he proposed to divert into the Juncal. It can not be definitely stated what space of time he meant to include within this period, but as his report bears date July 21, 1896, it is probable that these measurements extend from the 1st of November, 1895, to say the 1st of July, 1896. The rainfall during that winter was 13.77 inches at Santa Barbara, and his conclusion can not be accepted that this record may be taken as an approximate minimum for streams in the Santa Ynez Mountains, particularly as there was at Santa Barbara in the month of January a precipitation of 6.84 inches, which should, in all probability, have yielded a flood condition in the streams.

Purslow's surveys of the capacity of the Juncal reservoir site practically confirm those by Wright, already stated. The site is one of considerable merit, and possibly the dam should be built ultimately in connection with supplementing the storage capacity of the lower dams. The Gibraltar reservoir site, below the Mono on the trunk stream, however, offers a very much cheaper storage capacity and a much larger available supply. Purslow probably overestimates the underflow at the Main River site.

Purslow proposes using a riveted-steel pressure pipe line to divert the water to Santa Barbara; probably the life of this pipe line would not be more than fifteen years. His detailed estimate of the cost is $300,000 to obtain water from the Juncal. The dam which he proposes is to be 100 feet high, with a storage capacity of 1,023 million gallons. He estimates the minimum season's supply as 400 million gallons, and considers an annual draft of 600 million gallons (equal to 1,845 acre-feet) as the amount that might be obtained from the reservoir with that dam.

It is here estimated that the run-off from the Juncal would have been in minimum years as follows:

Run-off from Juncal reservoir.

	Acre-feet.
1869-70	603
1870-71	335
1897-98	0
1898-99	1,114
1899-1900	1,367

It must be remembered that these estimates are only approximations based upon observations on other streams somewhat similarly situated and are not absolute. However, they are believed to be fair conclusions from the best available data, and, using them, we can not accept the conclusion that 1,845 acre-feet of water could annually be withdrawn from this reservoir site. This, however, does not condemn the site, if it is used in connection with the lower site to supplement the supply in dry years. It is believed that ultimately this reservoir may be constructed for this purpose, but it is not believed that it is wise to base a water supply for the city of Santa Barbara on it alone with its drainage basin of but 13 square miles.

REPORT OF R. B. CANFIELD, 1896.

On July 28, 1896, Mr. R. B. Canfield, president of the Santa Barbara Water Company, made a report supplemental to that of Purslow. Mr. Canfield's conclusions are also of interest because of his intimate and accurate knowledge of the water situation near Santa Barbara, on the south of the Santa Ynez Mountains. It must be remembered that the measurements of Wright to which he refers were made in a year of excessive stream flow.

Canfield says:

> Mr. Wright found all the streams east of Santa Barbara, together with Mission Creek—9 streams in all—to be yielding daily 1,650,000 gallons, and the 15 creeks west of Mission Creek, to and including the Refugio, to be yielding daily 1,725,000 gallons, but he justly dismisses the idea of obtaining the needed supply from these sources as impracticable, partly owing to the expense of gathering and conveying the supply from so many points and over so long distances, and partly owing to the fact that all this water is claimed by riparian owners and individual water claimants and water companies organized to supply districts adjacent to some of the streams. It is well known that the demand for this water, especially in the neighborhood of this city, is beyond the capacity of all the streams to supply, and it is obvious that the expense of obtaining water from these sources would be prohibitive.
>
> All the streams (excepting the flow of the Hot Springs) on the south slope of the range east of Mission Creek as far as Romero Canyon, 8 miles distant, were yielding when measured in the summer of 1889 a total daily flow of 500,000 gallons, while the creeks west of Mission Canyon to and including San Jose Creek, 7 miles distant, were yielding a total daily flow of only 475,000 gallons, notwithstanding the comparatively abundant rainfall of preceding seasons. Even though these were the minimum quantities to be obtained in the dry season from these streams (which is far from being the case) and it were possible to bring them all to Santa Barbara for the supply of the city, whether by surface diversion or by means of tunnels in their neighborhood, which would intercept the supplies and drain their channels, it would not be desirable to do so. Santa Barbara, if she could afford the expense necessary for the acquisition of these waters, could not afford the loss she would suffer by the destruction of the prosperity and beauty of her suburbs of Montecito and Goleta. The prosperity of Santa Barbara depends in a large measure upon that of the neighboring rural districts, as does theirs upon that of the city. To the extent to which the city deprives the suburbs of their natural water supply, it injures itself.
>
> During the last spring borings were made under the direction of the city engineer west of the city in the hope of finding considerable underground currents, but without success. The subterranean waters in the eastern part of the ctiy are tapped by the wells of the Santa Barbara Water Company for the supply of its pumping plant; but all efforts to obtain the large additional supply which the city needs from these and other sources have

only tended to confirm the soundness of Mr. Wright's conclusion when he said: "I consider Santa Ynez River above the mouth of Blue Canyon to be not only an available source of supply, but the only source possible for the future supply of Santa Barbara with an abundance of good potable water."

Water is now sold in Santa Barbara at the rate of about 16 cents per thousand gallons to the city for street-sprinkling purposes (at the rate of $35,000 per year for 1 second-foot) and to private consumers at from 20 to 25 cents per thousand gallons, which are moderate rates as compared with those realized in some other cities in this State; and it is believed that although the development of the business in the future may justify some reduction of rates, an average rate of 15 cents per thousand gallons at least can be calculated upon. The city requires for its immediate needs at least 1,000,000 gallons of water daily, and its steady growth, soon to be accelerated by the completion of the railroad to San Francisco, will be constantly increasing this demand.

REPORT OF J. LINN MOYER, 1902.

MONO SITE.

On August 5, 1902, Mr. J. Linn Moyer, city engineer of Santa Barbara, made a report based on a reconnaissance through portions of the drainage basin of Santa Ynez River, particularly examining a new reservoir site suggested by Mr. Frank E. Kellogg, which the latter had observed on Mono Creek, the largest tributary of the upper portion of Santa Ynez River. Moyer made a favorable report on this situation, based on this reconnaissance, and made recommendations that further examinations be made. It was his judgment that the reservoir site, which is called the Mono site, was a good one and that the water supply available would be ample to meet the necessities of the city. Pls. III, *A*, and IV, *A*, *B*, show views of the Mono dam and reservoir sites. He recommended as follows:

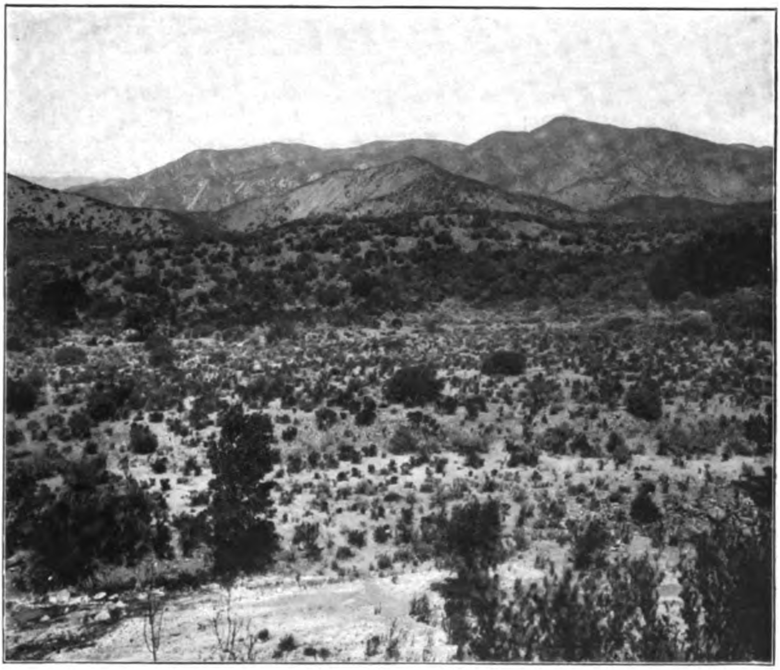
1. That the exact elevation of the dam site be determined in order to ascertain whether or not the water could be conducted to the city tunnel.
2. That borings and excavations be made on the dam site to ascertain the depth of bed rock and the quality of same.
3. That a topographical survey be made of the reservoir basin in order to determine the height necessary to construct the dam, and also to determine the amount and location of land necessary to be purchased.
4. That an option be obtained on the land necessary to be purchased, as will be shown by the topographical survey.
5. That a chemical analysis be made of the waters of Mono Creek.
6. That the grade of the present city tunnel be reduced to the lowest possible rate.

Moyer found that a provision should be made to furnish a continuous supply of 1 million gallons per day in addition to the present flow of the tunnel in order to fully supply the entire present population of the city.

CONCLUSIONS DRAWN FROM FOREGOING REPORTS.

The foregoing reports have been reviewed in extenso because doing so brings these investigations up to date and also because they furnish a proper basis from which to start on the present investigations. It

A. MONO DAM SITE, LEFT ABUTMENT.



B. MONO CREEK RESERVOIR SITE.

View upstream from dam site.

will be seen that all of these distinguished authorities, each one of whom was intimately acquainted with the local situation, agree on the following vital points:

1. That the present supply of water for the city of Santa Barbara is inadequate and that unless it is increased the material development of the town will be seriously impeded.

2. That there is no adequate water supply within a reasonable limit of the city of Santa Barbara on the south side of the range from which the city could be supplied, and even if the water of such small streams as there are could be obtained it would be at a sacrifice of existing development.

3. That it is feasible and desirable to obtain an adequate supply of water from the drainage basin of Santa Ynez River, and that this can be done at a profit.

The writer has, therefore, taken up the consideration of the subject at this point and prepared estimates of cost, etc.

POPULATION AND CONSUMPTION OF WATER.

The population of Santa Barbara, according to the enumeration of the United States Census, is as follows:

Population of Santa Barbara.

1870	2,889
1880	3,460
1890	5,864
1900	6,587
1905 (estimated)	10,000
1910 (estimated)	12,500

The rate of growth of Santa Barbara was most rapid from 1880 to 1890, but it has always shown a substantial increase in population. Projecting it into the future we obtain the populations for 1905 and 1910 as stated above. It is believed by the other engineers, as well as the writer, that the development of the city is largely dependent upon an adequate water supply, not only in the city but upon the adjacent suburban property. If this is once obtained it may be expected that the population will more rapidly increase. Among people looking for future homes, especially in the West, the water question is considered one of prime importance in the selection of a residence. At present (1903) the municipal waterworks has some 709 taps through which water is served, and the Santa Barbara Water Company has about 900, making a total of 1,609 taps, serving a population of about 8,045 persons. The Gates system supplies 50 taps more.

In May, 1902, 301 meters of the municipal waterworks indicated 81 gallons per capita daily consumption. In June, 1902, 329 meters indicated a consumption of 82 gallons per capita. In July, 1902, 369 meters indicated a consumption of 75.5 gallons per capita per day.

It will be seen that 55 per cent of the city's services are metered. It is estimated that 15 gallons per capita per day, not included in the above rate, are used in public buildings and in street sprinkling. It would probably be fair to say, using round numbers, that the present consumption of the city is 100 gallons per capita per day. This is a rather low rate of consumption for a California city, and in all probability the city would use to advantage more water if it were available at reasonable prices. The consumption in Los Angeles before meters were introduced, in the summer of 1901, was 306 gallons per capita per day. After the introduction of several thousand meters it is now 242 gallons per capita per day. The water commissioners of that city in their annual report for 1902 estimate that a reasonable consumption would be 150 gallons per capita per day for metered services. The city of San Jose, in 1890, was using 194 gallons per capita daily. Wright, in his report to the city, estimated on a consumption of 200 gallons, and Purslow considered that 130 gallons should be sufficient.

Considering the evidence in the case, it is believed that it is desirable, for the proper development of the city, improvements of lawns, gardens, etc., that 150 gallons daily, as an average for the year, should be used, and this has been adopted as a proper basis for this report.

In considering the storage of flood waters necessary to meet this situation, it has been estimated that 60 per cent of the water supply would be used in the six summer months, and 40 per cent in the six winter months. The question of evaporation from reservoirs is an important one in estimating on a storage system. It is believed that the annual evaporation from reservoirs in the basin of the Santa Ynez would be approximately 42 inches in depth, 67½ per cent of this occurring in the six summer months, and 32½ per cent in the six winter months. From a study of the monthly rainfall tables of precipitation occurring at Santa Barbara (see table 11) it appears that there would, in all probability, have been no material addition to the waters stored in any reservoirs in this locality from May 1, 1876, to December 1, 1877, a period of nineteen months. Again, between April 1, 1897, and October 1, 1898, or for a period of eighteen months, there would have been no material addition. It will be necessary, therefore, in order to prepare for the worst condition that will probably occur in the future, as judged by a record of thirty-six years' rainfall in the past, to construct reservoirs that will hold a supply of water for a period of nineteen months of continuous withdrawal without replenishment.

With a population of 10,000 persons in 1905, reasonably within sight and necessary to immediately prepare for, at 150 gallons per day, there will be a consumption of 1,500,000 gallons daily. This amount of water withdrawn for a period of nineteen months will require 2,826[a] acre-feet for actual domestic uses. It is also necessary to provide for a loss by evaporation of about 692 acre-feet (for a reservoir of this size for nineteen months), or a total of 3,518 acre-feet for use and evaporation during the worst period of drought that the city will probably ever have to face.

Reducing it to a monthly withdrawal, there will be required for summer use 170 acre-feet, for summer evaporation about 45 acre-feet, and for summer use and evaporation 215 acre-feet.

From surveys that have been made of the reservoirs, described later in this report, it appears that a dam 85 feet high at the Mono site, impounding water to a depth of 75 feet, will give storage capacity for 3,880 acre-feet of water—enough to meet the above needs, even assuming the severe conclusions that no permanent supply can be relied upon from the tunnel, and that the municipality is to furnish all the water for the town. Similarly a dam 100 feet high at the Gibraltar site (see p. 55) would give an equal capacity and have tributary thereto a larger and better water supply.

NEAR-BY SUPPLIES.

The question of local water supply on the south side of the range was extensively discussed under the review of the reports of Wright, Purslow, and Canfield. Generally speaking, the amount now available for the city may be taken in average years as 300,000 gallons daily from Mission Creek, 300,000 gallons from the De la Guerra wells (statement by Purslow), and 350,000 gallons from the city tunnel, making 950,000 gallons to meet an estimated normal present demand of 1,200,000[b] gallons, or a deficit daily of 250,000 gallons.

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[a] One acre-foot is equivalent to 325,851 gallons.

[b] On basis of 150 gallons per day for 8,000 persons.

MISSION CREEK.

The following measurements of Mission Creek taken at various times, as stated, may be of interest in this connection:

TABLE 4.—*Discharge measurements on Mission Creek.*

Date.	Hydrographer.	Discharge in second-feet.[a]	Gallons per day.
1888.			
Jan. 15	A. Poett	0.93	605,594
24	....do	2.80	18,200,000
Feb. 7	....do	1.37	888,552
Mar. 16	....do	2.23	1,452,000
July 26	....do	.36	233,000
29	....do	.28	184,747
1889.			
July 13	....do	.43	282,609
17	....do	.36	232,551
Aug.	G. F. Wright	.34	219,672
18	A. Poett	.21	137,052
Sept. 1	....do	.32	206,821
1892.			
June 11	....do	.36	232,673
1894.			
June 28	Flourney	.24	155,115
1900.			
May 10	....do	.25	161,600
June 17	L. Moyer	.045	[b] 29,084

[a] One second-foot is equivalent to 50 miner's inches.

[b] Above diversion not on bed rock, 200 feet above dam.

TABLE 5.—*Measurements in Mission Canyon.*

[50 miner's inches=1 cubic foot per second.]

AT NOTCHED WEIR NEAR PORTAL OF PROPOSED NEW CITY MISSION TUNNEL.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Aug. 14	2.30 p. m.	R. L. North and J. Compton	6.367
15	8.30 a. m.	....do	9.474
15	9 a. m.	....do	8.817
15	9.30 a. m.	....do	8.817
15	10 a. m.	....do	8.689
15	10.30 a. m.	....do	8.140

TABLE 5.—*Measurements in Mission Canyon*—Continued.

AT NOTCHED WEIR NEAR PORTAL OF PROPOSED NEW CITY MISSION TUNNEL—C't'd.

Date.		Time.	Hydrographer.	Discharge in inches.
1903.				
Aug.	15	11 a. m.	R. L. North and J. Compton	7.823
	15	11.30 a. m.	do.	7.832
	15	12 m.	do.	7.242
	15	12.30 p. m.	do.	6.959
	15	1 p. m.	do.	6.363
	15	1.30 p. m.	do.	6.109
	15	2 p. m.	do.	5.600
	15	2.30 p. m.	do.	5.359
	15	3. p. m.	do.	5.220
	15	3.30 p. m.	do.	4.851
	15	4 p. m.	do.	4.851
	15	4.30 p. m.	do.	4.851
	15	5 p. m.	do.	5.042

AT OLD MISSION DAM.

1903.				
Aug.	22	6.30 p. m.	L. M. Hyde and R. L. North	0.909
	23	9.10 a. m.	do.	4.762
	24	8.25 a. m.	L. M. Hyde, R. L. North, and G. D. Morrison	8.333
	24	6.15 p. m.	do.	6.896
	25	7.45 a. m.	L. M. Hyde and R. L. North	10.000
	27	7.15 a. m.	R. L. North, R. F. Wyckoff, and G. D. Morrison	10.000

AT NOTCHED WEIR AS ABOVE.

1903.				
Aug.	27	8.30 a. m.	R. L. North and R. F. Wyckoff	9.080
	27	9 a. m.	do.	9.080
	27	1 p. m.	do.	7.070
	27	1.30 p. m.	do.	6.420
	27	2 p. m.	do.	5.750
	27	2.30 p. m.	do.	5.750
	27	3 p. m.	do.	5.410
	27	3.30 p. m.	do.	4.950
	27	4 p. m.	do.	4.990
	27	4.30 p. m.	do.	4.990
	27	5 p. m.	do.	4.810

TABLE 5.—*Measurements in Mission Canyon*—Continued.

AT OLD MISSION DAM.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Oct. 3	2.20 p. m.	J. L. Moyer, T. B. Curley, and D. Boyle	5.320

AT NOTCHED WEIR AS ABOVE.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Oct. 19	8 a. m.	L. M. Hyde and C. M. Elliott	7.532
19	8.30 a. m.	do	7.356
19	9 a. m.	do	6.742
19	9.30 a. m.	do	6.314
19	10 a. m.	do	6.158
19	10.30 a. m.	do	6.003
19	11 a. m.	do	6.003
19	11.30 a. m.	do	5.803
19	12 m.	do	5.600
19	12.30 p. m.	do	5.317
19	1 p. m.	do	5.042
19	1.30 p. m.	do	4.810
19	2 p. m.	do	4.591
19	2.30 p. m.	C. M. Elliott	4.591
19	3 p. m.	do	4.378
19	3.30 p. m.	do	4.255
19	4 p. m.	do	4.169
19	4.30 p. m.	do	4.169
19	5 p. m.	do	3.970
Nov. 4	8.30 a. m.	G. D. Morrison	8.817
4	9 a. m.	do	8.753
4	9.30 a. m.	do	7.708
4	10 a. m.	do	7.416
4	10.30 a. m.	do	7.187
4	11 a. m.	do	6.852
4	11.30 a. m.	do	6.792
4	12 m.	do	6.579
4	12.30 p. m.	do	6.579
4	1 p. m.	do	6.261
4	1.30 p. m.	do	6.003
4	2 p. m.	do	6.003
4	2.30 p. m.	do	5.853
4	3 p. m.	do	5.903
4	3.30 p. m.	do	5.600

TABLE 5.—*Measurements in Mission Canyon*—Continued.

AT NOTCHED WEIR AS ABOVE—Continued.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Nov. 4	4 p. m.	G. D. Morrison	5.750
4	4.30 p. m.	do.	5.600
16	8.30 a. m.	R. F. Wyckoff	8.689
16	9 a. m.	do.	7.945
16	9.30 a. m.	do.	7.299
16	10 a. m.	do.	7.242
16	10.30 a. m.	do.	6.595
16	11 a. m.	do.	6.792
16	11.30 a. m.	do.	6.687
16	12 m.	do.	6.420
16	12.30 p. m.	do.	6.314
16	1 p. m.	do.	6.314
16	1.30 p. m.	do.	5.853
16	2 p. m.	do.	5.600
16	2.30 p. m.	do.	5.269
16	3 p. m.	do.	5.131
16	3.30 p. m.	do.	4.950
16	4 p. m.	do.	4.851
16	4.30 p. m.	do.	4.680
28	8.30 a. m.	R. L. North	6.370
28	9 a. m.	do.	6.690
28	9.30 a. m.	do.	6.000
28	10 a. m.	do.	5.900
28	10.30 a. m.	do.	5.650
28	11 a. m.	do.	5.650
28	11.30 a. m.	do.	5.510
28	12 m.	do.	5.510
28	1 p. m.	do.	5.040
28	1.30 p. m.	do.	4.850
28	2 p. m.	do.	4.720
28	2.30 p. m.	do.	4.680
28	3 p. m.	do.	4.680
28	3.30 p. m.	do.	4.340
28	4 p. m.	do.	4.300
28	4.30 p. m.	do.	4.130
28	5 p. m.	do.	3.970
Dec. 24	10.30 a. m.	G. D. Morrison	7.470
24	11 a. m.	do.	6.560
24	11.30 a. m.	do.	6.370

TABLE 5.—*Measurements in Mission Canyon*—Continued.

AT NOTCHED WEIR AS ABOVE—Continued.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Dec. 24	12 m.	G. D. Morrison	6.210
24	12.30 p. m.	....do.	6.160
24	1 p. m.	....do.	6.160
24	1.30 p. m.	....do.	5.950
24	2 p. m.	....do.	5.600
24	2.30 p. m.	....do.	5.460
24	3 p. m.	....do.	5.320
24	3.30 p. m.	....do.	5.080
24	4 p. m.	....do.	5.040
1904.			
Feb. 29	11.15 a. m.	L. M. Hyde	18.190
Mar. 14	3.30 p. m.	....do.	16.310

AT OLD MISSION DAM.

Date.	Time.	Hydrographer.	Discharge in inches.
1904.			
Apr. 4	....	L. M. Hyde	16.670

TABLE 6.—*Measurements in Rattlesnake Canyon.*

AT NOTCHED WEIR ABOUT 200 FEET UPSTREAM FROM WHERE WATER IS DIVERTED FOR SANTA BARBARA WATER SUPPLY.

[50 miner's inches=1 cubic foot per second.]

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Aug. 17	8.30 a. m.	R. L. North and J. Compton	2.507
17	9 a. m.	....do.	2.596
17	9.30 a. m.	....do.	2:507
17	10 a. m.	....do.	2.216
17	10.30 a. m.	....do.	2.216
17	11 a. m.	....do.	2.216
17	11.30 a. m.	....do.	2.261
17	12 m.	....do.	2.261
17	12.30 p. m.	....do.	2.216
17	1 p. m.	....do.	2.261
17	1.30 p. m.	....do.	2.216
17	2 p. m.	....do.	2.216

TABLE 6.—*Measurements in Rattlesnake Canyon*—Continued.

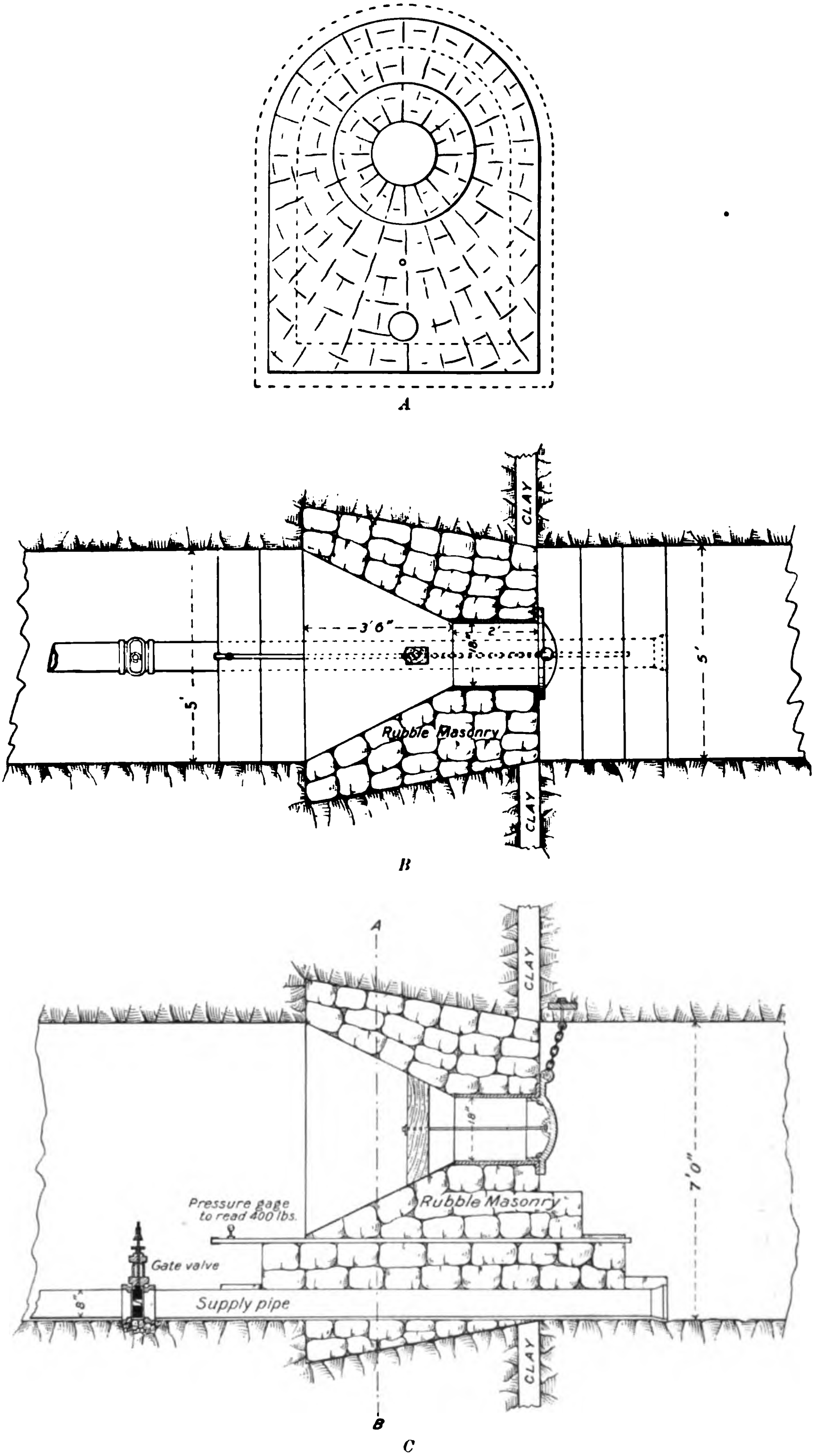
AT NOTCHED WEIR ABOUT 200 FEET UPSTREAM FROM WHERE WATER IS DIVERTED FOR SANTA BARBARA WATER SUPPLY—Continued.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Aug. 17	2.30 p. m	R. L. North and J. Compton	2.132
17	3 p. m	do	2.080
17	3.30 p. m	do	2.080
17	4 p. m	do	2.080
17	4.30 p. m	do	2.080
17	5 p. m	do	2.216
Oct. 3	3.45 p. m	J. L. Moyer, T. B. Curley, and D. Boyle	2.261
19	8.30 a. m	R. L. North	1.772
19	9 a. m	do	1.627
19	9.30 a. m	do	1.492
19	10 a. m	do	1.582
19	10.30 a. m	do	1.471
19	11 a. m	do	1.582
19	11.30 a. m	do	1.582
19	12 m	do	1.302
19	12.30 p. m	do	1.448
19	1 p. m	do	1.403
19	1.30 p. m	do	1.242
19	2 p. m	do	1.471
19	2.30 p. m	do	1.302
19	3 p. m	do	1.262
19	3.30 p. m	do	1.403
19	4 p. m	do	1.514
19	4.30 p. m	do	1.448
19	5 p. m	do	1.514
Nov. 3	9.30 a. m	G. D. Morrison	1.871
3	10 a. m	do	1.847
3	10.30 a. m	do	1.897
3	11 a. m	do	1.822
3	11.30 a. m	do	1.797
3	12 m	do	1.797
3	12.30 p. m	do	1.746
3	1 p. m	do	1.772
3	1.30 p. m	do	1.772
3	2 p. m	do	1.651
3	2.30 p. m	do	1.746
3	3 p. m	do	1.722
3	3.30 p. m	do	1.722
3	4 p. m	do	1.772

TABLE 6.—*Measurements in Rattlesnake Canyon*—Continued.

AT NOTCHED WEIR ABOUT 200 FEET UPSTREAM FROM WHERE WATER IS DIVERTED FOR SANTA BARBARA WATER SUPPLY—Continued.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Nov. 3	4.30 p. m.	G. D. Morrison	1.772
15	9 a. m.	R. F. Wyckoff	2.360
15	9.30 a. m.	do	2.360
15	10 a. m.	do	2.272
15	10.30 a. m.	do	2.160
15	11 a. m.	do	2.160
15	11.30 a. m.	do	2.132
15	12 m.	do	2.132
15	12.30 p. m.	do	2.080
15	1 p. m.	do	2.080
15	1.30 p. m.	do	2.080
15	2 p. m.	do	1.972
15	2.30 p. m.	do	2.051
15	3 p. m.	do	2.080
15	3.30 p. m.	do	2.051
15	4 p. m.	do	2.051
15	4.30 p. m.	do	2.080
28	8.30 a. m.	G. D. Morrison	2.160
28	9 a. m.	do	2.110
28	9.30 a. m.	do	2.030
28	10 a. m.	do	2.050
28	10.30 a. m.	do	2.000
28	11 a. m.	do	1.950
28	11.30 a. m.	do	1.950
28	12 m.	do	1.900
28	12.30 p. m.	do	1.950
28	1 p. m.	do	1.900
28	1.30 p. m.	do	1.850
28	2 p. m.	do	1.820
28	2.30 p. m.	do	1.820
28	3 p. m.	do	1.770
28	3.30 p. m.	do	1.720
28	4 p. m.	do	1.750
Dec. 23	9 a. m.	do	2.510
23	9.30 a. m.	do	2.510
23	10 a. m.	do	2.480
23	10.30 a. m.	do	2.480
23	11 a. m.	do	2.390
23	11.30 a. m.	do	2.360



BULKHEAD AND DISCHARGE PIPES IN OLD CITY TUNNEL, COLD SPRINGS CANYON.

A, End view; *B*, plan; *C*, longitudinal section.

TABLE 6.—*Measurements in Rattlesnake Canyon*—Continued.

AT NOTCHED WEIR ABOUT 200 FEET UPSTREAM FROM WHERE WATER IS DIVERTED FOR SANTA BARBARA WATER SUPPLY—Continued.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Dec. 23	12 m.	G. D. Morrison	2.360
23	12.30 p. m.	do	2.270
23	1 p. m.	do	2.270
23	1.30 p. m.	do	2.330
23	2 p. m.	do	2.360
23	2.30 p. m.	do	2.360
23	3 p. m.	do	2.360
23	3.30 p. m.	do	2.390
23	4 p. m.	do	2.450
1904.			
Apr. 7	1.45 p. m.	L. M. Hyde	12.460

DE LA GUERRA WELLS.

At the De la Guerra pumping station there are seven cased wells from 200 to 700 feet deep. These discharge into a concrete well 25 feet in diameter and 30 feet deep, having a capacity of 110,160 gallons. This well fills during the night and is pumped out during the day. If the wells are considered as discharging as much during the day as they do during the night when the tank is filling, their flow at present is about 220,000 gallons daily and is (in 1903) decreasing. As the pumps run more than twelve hours each day the output is correspondingly greater. There is installed at this station one Prescott pump of 1½ million gallons nominal capacity and one Worthington pump of 1 million gallons capacity daily. The pumps discharge directly into the city mains and work against a pressure head of from 100 to 120 pounds. Mr. Wright states that in August, 1889, a six-day test of these wells indicated a capacity of 600,000 gallons daily. It is stated that these wells afterwards failed and that deeper wells were then sunk, from which the present supply is now obtained.

CITY TUNNEL.

In the month of January, 1896, the city of Santa Barbara started a tunnel for the development of water in sec. 36, T. 5 N., R. 26 W., San Bernardino meridian. The tunnel has been successful in this particular and has been of inestimable service to the city in sustaining it through the period of intense drought of the last few years. The tunnel is 7 feet high and 5 feet wide at the base. The elevation of the portal is approximately 1,400 feet above sea level, and it was driven for the first 4,800 feet of its length on a grade of 1 foot in 100. The purpose in running the tunnel at first was solely to develop water and not with the intention of extending it on through the mountains. It will be noted from the table of discharge that during its construction the discharge was surprisingly constant, irrespective of length. Enough water is thus obtained for a number of consumers, but not enough to supply a large town or city. The amount of water which was extracted from the mountain was sufficient to pay for the cost of the excavation. It is quite possible that in years of ordinary rainfall the unregulated flow of water from the tunnel would have been more constant, but the years of construction were ones of unusual drought. However, from the fact that the water supply has not been materially increased by lengthening the tunnel, and that the flow of the water pays for the cost of the work, it has been a natural and logical sequence that the city should contemplate the extension of this or some other tunnel entirely through the Coast Range into the drainage basin of the Santa Ynez in order to make available the water of this large mountainous area. The tunnel work has been carried on with intelligence, the power from the water coming therefrom being conducted through pressure pipes and used for the running of drills for the excavation work.

COST OF TUNNEL.

As a guide to what the city may expect in the future, the expense of doing this tunnel work is of interest. It will be noted that there has been variation in the cost, owing to local conditions of the labor market, etc. The city has installed the machinery necessary for doing the work, and the contractor has furnished the labor and material necessary for its prosecution at the rate named in the table.

TABLE 7.—*Cost of labor and material in driving city tunnel.*

Distance excavated.	Price per foot.	Distance excavated.	Price per foot.
Feet.		*Feet.*	
0 to 1,000	$5.50	1,642 to 1,750	....
1,000 to 1,146	7.50	1,750 to 1,786½	$13.76
1,146 to 1,202	8.73	1,786½ to 2,286	9.30
1,202 to 1,276½	7.58	2,286 to 2,572	10.00
1,276½ to 1,363½	6.89	2,572 to 3,072	10.75
1,363½ to 1,434½	8.25	3,072 to 3,572	10.48
1,434½ to 1,500	9.00	3,572 to 4,072	9.17
1,500 to 1,582	....	4,072 to 5,072	9.00
1,582 to 1,642	9.00		

DISCHARGE OF TUNNEL.

The tunnel is run in a sandstone and shale formation characteristic of the Coast Range, the rock being considerably broken and somewhat stratified. As the work progresses many crevices and cavities in the rock filled with water, probably from rainfall, are found, and as the tunnel cuts the various lines of cleavage these underground reservoirs are tapped. The actual rock is not of a very porous nature and in itself does not yield much water, but it is believed that these cavities will be refilled, at least in part, by subsequent rains and that a material amount of water can be permanently withdrawn from the tunnel. If the city does obtain a supply therefrom permanently there will be just that much more water at its disposal, and there certainly is a market for it all, either in the city or on adjoining agricultural lands.

The water is led from the tunnel to two city reservoirs, each with a capacity of 1,600,000 gallons, situated at an elevation of 350 feet above the city datum plane.

The power now available at the tunnel for driving the drills and blowers is inadequate for its continuation. Generally speaking, it requires from 10 to 12 horsepower to run each air drill, not including the power for the blowers for ventilation.

In order to regulate the flow of water from this tunnel after the last contract was finished, to the 5,000-foot point from the heading, a bulkhead was designed by the author and placed in the tunnel about 800 feet from the portal. During the winter of 1902–3 there was a fair amount of rainfall and the streams were capable during that time of meeting the demands of the city. As soon as the bulkhead could be closed this was done—about July 1, 1903.

Because of the fissured condition of the rock in the tunnel it was not feasible at the point where the bulkhead was first placed to completely close the supply from the heading, as springs occurred below the bulkhead toward the portal, flowing in considerable volume. However, the pressure ran up to 49 pounds to the square inch on July 25, as recorded by the pressure gage placed in the discharge pipe, indicating an accumulated head of water back of the bulkhead of 114 feet. This shows that the tunnel was developed into a storage reservoir. The gate valve in the bulkhead was gradually opened as the season progessed, and the supply maintained a flow of from 24 to 33 miner's inches during the remainder of the summer. On October 17, when the valve was completely opened and the pressure had been reduced to zero, the flow had fallen to 24 miner's inches. This was sufficient to carry the city through the summer successfully.

During the winter of 1903–4 a new bulkhead was placed at a point in the tunnel where a heavy clay seam occurs in the rock. This new bulkhead was more effective than the first one constructed in holding back the water. It is hoped that this will form an impervious barrier against the passage of the ground water, thus enabling the tunnel to accumulate a high head of water.[a]

Table 8a shows the variation in volume discharged from the tunnel, as well as the pressure in pounds per square inch, as the season advances.

TABLE 8.—*Flow of water from city tunnel.*

Date.	Length of tunnel in feet.	Flow in miner's inches.[b]	Flow in gallons per day.
1900.			
May 1	2,952	25.00	323,125
July 26	3,078	19.00	245,575
August 1	3,103	19.00	245,575
October 27	3,267	20.00	258,500
November 4	3,280	25.00	323,125
1901.			
January 9	3,393	38.00	491,150
February 1	3,448	50.00	646,250
February 28	3,561	63.33	818,583
April 1	3,614	55.00	710,875
May 1	3,680	45.00	581,625
June 1	3,740	45.00	581,625
July 1	3,792	[c]35.00	452,375
August 1	3,865	30.00	387,750
1902.			
February 4	4,182	30.00	387,750
March 4	4,256	30.00	387,750
March 31	4,309	33.00	426,525
April 29	4,367	30.00	387,750
June 7	4,509	24.00	310,200
July 25	4,560	25.50	329,588
August 4	4,578	27.75	358,669
September 2	4,647	30.30	391,628
December 1	4,832	30.00	387,750

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[a] 24.59 inches of rain fell at Montecito between September 24, 1904, and March 3, 1905, and the pressure on the tunnel bulkhead had increased to 80 pounds per square inch.

[b] 50 miner's inches are equivalent to 1 second-foot, and 1 miner's inch to 12,925 gallons per day.

[c] Estimated.

TABLE 8a.—*Daily mean head over 18-inch weir, and discharge, of Santa Barbara tunnel, 1903.*[a]

Day	January.				February.				March.				April.			
	Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.		
		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.
1	0.191	0.405	20.25	261,758	0.210	0.469	23.45	303,122	0.271	0.679	33.95	438.848	0.292	0.756	37.80	488,614
2	.193	.412	20.60	266,282	.214	.482	24.10	311,524	.270	.675	33.75	436,263	.326	.890	44.50	575,220
3	.195	.418	20.90	270,160	.218	.493	24.65	318,633	.270	.675	33.75	436,263	.370	1.068	53.40	690,264
4	.195	.418	20.90	270,160	.217	.489	24.45	316,048	.269	.971	33.55	433,677	.371	1.072	53.60	692,850
5	.195	.418	20.90	270,160	.214	.482	24.10	311,524	.269	.671	33.55	433,677	.369	1.064	53.20	687,679
6	.195	.418	20.90	270,160	.210	.469	23.45	303,122	.268	.668	33.40	431,738	.365	1.046	52.30	676,045
7	.195	.418	20.90	270,160	.214	.482	24.10	311,524	.268	.668	33.40	431,738	.361	1.032	51.60	666,997
8	.195	.418	20.90	270,160	.220	.500	25.00	323,158	.267	.664	33.20	429,153	.357	1.016	50.80	656,656
9	.195	.418	20.90	270,160	.227	.524	26.20	338,669	.267	.664	33.20	429,153	.354	1.003	50.15	648,254
10	.195	.418	20.90	270,160	.235	.553	27.65	357,412	.266	.660	33.00	426,568	.352	.995	49.75	643,083
11	.195	.418	20.90	270,160	.234	.549	27.45	354,827	.266	.660	33.00	426,568	.350	.986	49.30	637,267
12	.200	.435	21.75	281,147	.231	.538	26.90	347,717	.265	.656	32.80	423,983	.346	.969	48.45	626,279
13	.204	.448	22.40	289,549	.228	.528	26.40	341,254	.265	.656	32.80	423,983	.344	.961	48.05	621,109
14	.200	.435	21.75	281,147	.232	.542	27.10	350,303	.264	.653	32.65	422,044	.342	.954	47.70	616,585
15	.200	.435	21.75	281,147	.238	.560	28.00	361,936	.264	.653	32.65	422,044	.340	.947	47.35	612,060
16	.200	.435	21.75	281,147	.246	.589	29.45	380,680	.263	.650	32.50	420,105	.338	.940	47.00	607,536
17	.200	.435	21.75	281,147	.254	.618	30.90	399,423	.263	.650	32.50	420,105	.341	.944	47.20	610,121
18	.200	.435	21.75	281,147	.247	.592	29.60	382,618	.264	.653	32.65	422,044	.350	.986	49.30	637,267
19	.202	.442	22.10	285,671	.240	.567	28.35	366,461	.264	.653	32.65	422,044	.350	.986	49.30	637,267
20	.204	.448	22.40	289,549	.240	.567	28.35	366,461	.266	.660	33.00	426,568	.350	.986	49.30	637,267
21	.205	.452	22.60	292,134	.249	.600	30.00	387,789	.266	.660	33.00	426,568	.350	.986	49.30	637,267
22	.205	.452	22.60	292,134	.256	.626	31.30	404,593	.265	.656	32.80	423,983	.350	.986	49.30	637,267
23	.205	.452	22.60	292,134	.257	.630	31.50	407,178	.265	.656	32.80	423,983	.350	.986	49.30	637,267
24	.205	.452	22.60	292,134	.261	.645	32.25	416,873	.263	.650	32.50	420,105	.350	.986	49.30	637,267
25	.205	.452	22.60	292,134	.259	.637	31.85	411,703	.262	.647	32.35	418,166	.350	.986	49.30	637,267
26	.207	.459	22.95	296,659	.258	.633	31.65	409,117	.262	.647	32.35	418,166	.350	.986	49.30	637,267
27	.210	.469	23.45	303,122	.257	.630	31.50	407,178	.262	.647	32.35	418,166	.349	.982	49.10	634,681
28	.214	.482	24.10	311,524	.265	.656	32.80	423,983	.266	.660	33.00	426,568	.351	.990	49.50	639,852
29	.212	.476	23.80	307,646					.268	.668	33.40	431,738	.350	.986	49.30	637,267
30	.209	.465	23.25	300,536					.269	.671	33.55	433,677	.348	.978	48.90	632,096
31	.207	.459	22.95	296,659					.278	.706	35.30	456,298				
Total				8,787,947				10,114,830				13,253,984				19,035,918
Average	.201	.439	21.93	283,482	.237	.559	27.95	361,244	.266	.662	33.06	427,548	.349	.982	49.09	634,531

[a] By the closing of the bulkhead during the spring of 1904 the water was again impounded in the tunnel and the flow regulated therefrom so as to sustain a fairly constant flow throughout the summer of 1904. Owing to the drought this was the main water supply of the city during that period.

TABLE 8a.—*Daily mean head over 18-inch weir, and discharge, of Santa Barbara tunnel, 1903*—Continued.

Day.	May.				June.				July.				August.			
	Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.		
		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.
1	0.354	1.003	50.15	648,254	0.302	0.796	39.80	514,467	0.326	0.890	44.50	575,220	0.307	0.816	40.80	527,393
2	.360	1.029	51.45	665,058	.300	.788	39.40	509,269	.326	.890	44.50	575,220	.318	.857	42.85	553,892
3	.362	1.036	51.80	669,582	.301	.792	39.60	511,881	.326	.890	44.50	575,220	.320	.865	43.25	559,062
4	.362	1.036	51.80	669,582	.302	.796	39.80	514,467	.326	.890	44.50	575,220	.326	.890	44.50	575,220
5	.358	1.021	51.05	659,888	.302	.796	39.80	514,467	.326	.890	44.50	575,220	.329	.902	45.10	582,976
6	.360	1.029	51.45	665,058	.300	.788	39.40	509,269	.300	.788	39.40	509,296	.329	.902	45.10	582,976
7	.363	1.039	51.95	671,521	.300	.788	39.40	509,269	.239	.563	28.15	363,875	.336	.932	46.60	602,366
8	.366	1.050	52.50	678,631	.300	.788	39.40	509,269	.225	.518	25.90	334,791	.333	.919	45.95	593,963
9	.366	1.050	52.50	678,631	.298	.780	39.00	504,126	.220	.500	25.00	323,158	.322	.873	43.65	564,233
10	.360	1.029	51.45	665,058	.292	.756	37.80	488,614	.220	.500	25.00	323,158	.321	.869	43.45	561,648
11	.360	1.029	51.45	665,058	.293	.760	38.00	491,199	.219	.496	24.80	320,572	.328	.898	44.90	580,391
12	.360	1.029	51.45	665,058	.278	.706	35.30	456,298	.219	.496	24.80	320,572	.290	.748	37.40	483,444
13	.358	1.021	51.05	659,888	.306	.812	40.60	524,808	.220	.500	25.00	323,158	.249	.600	30.00	387,789
14	.308	.820	41.00	529,978	.307	.816	40.80	527,393	.220	.500	25.00	323,158	.273	.687	34.35	444,018
15	.223	.510	25.50	329,621	.308	.820	41.00	529,978	.234	.549	27.45	354,827	.275	.694	34.70	448,543
16	.258	.633	31.65	409,117	.310	.828	41.40	535,149	.270	.675	33.75	436,263	.277	.702	35.10	453,718
17	.300	.788	39.40	509,296	.311	.832	41.60	537,734	.292	.756	37.80	488,614	.276	.698	34.90	451,128
18	.301	.792	39.60	511,881	.312	.836	41.80	540,319	.268	.668	33.40	431,738	.275	.694	34.70	448,543
19	.302	.796	39.80	514,467	.313	.840	42.00	542,905	.254	.618	30.90	399,423	.274	.690	34.50	445,957
20	.303	.800	40.00	517,052	.314	.843	42.15	544,844	.258	.633	31.65	409,117	.273	.687	34.35	444,018
21	.304	.804	40.20	519,637	.315	.847	42.35	547,429	.272	.683	34.15	441,433	.270	.675	33.75	436,263
22	.305	.808	40.40	522,223	.316	.850	42.50	549,368	.271	.679	33.95	438,848	.300	.788	39.40	509,296
23	.307	.816	40.80	527,393	.317	.853	42.65	551,307	.267	.664	33.20	429,158	.324	.881	44.05	569,404
24	.308	.820	41.00	529,978	.318	.857	42.85	553,892	.272	.683	34.15	441,433	.254	.618	30.90	399,423
25	.307	.816	40.80	527,393	.319	.861	43.05	556,477	.275	.694	34.70	448,543	.134	.241	12.05	155,762
26	.307	.816	40.80	527,393	.320	.865	43.25	559,062	.274	.690	34.50	445,957	.194	.415	20.75	268,221
27	.306	.812	40.60	524,808	.321	.869	43.45	561,648	.271	.679	33.95	438,848	.277	.702	35.10	453,718
28	.306	.812	40.60	524,808	.322	.873	43.65	564,233	.276	.698	34.90	451,128	.278	.706	35.30	456,298
29	.305	.808	40.40	522,223	.323	.877	43.85	566,818	.264	.653	32.65	422,044	.260	.641	32.05	414,288
30	.303	.800	40.00	517,052	.325	.885	44.25	571,989	.260	.641	32.05	414,288	.258	.633	31.65	409,117
31	.303	.800	40.00	517,052					.274	.690	34.50	445,957	.256	.626	31.30	404,593
Total				17,742,639				15,898,056				13,355,452				14,767,561
Average	.324	.886	44.28	572,342	.308	.820	41.00	529,935	.267	.667	33.33	430,821	.285	.737	36.85	476,373

Day.	September.				October.				November.				December.			
	Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.		
		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.
1	0.254	0.618	30.90	399,423	0.240	0.567	28.35	366,461	0.228	0.528	26.40	341,254	0.223	0.510	25.50	329,621
2	.252	.612	30.60	395,545	.238	.561	28.05	362,583	.228	.528	26.40	341,254	.222	.507	25.35	327,682
3	.250	.604	30.20	390,374	.260	.641	32.05	414,288	.228	.528	26.40	341,254	.222	.507	25.35	327,682
4	.250	.604	30.20	390,374	.276	.698	34.90	451,128	.228	.528	26.40	341,254	.222	.507	25.35	327,682
5	.248	.596	29.80	385,204	.260	.641	32.05	414,288	.228	.528	26.40	341,254	.222	.507	25.35	327,682
6	.248	.596	29.80	385,204	.250	.604	30.20	390,374	.228	.528	26.40	341,254	.222	.507	25.35	327,682
7	.248	.596	29.80	385,204	.244	.581	29.05	375,509	.228	.528	26.40	341,254	.222	.507	25.35	327,682
8	.248	.596	29.80	385,204	.241	.570	28.50	368,400	.228	.528	26.40	341,254	.222	.507	25.35	327,682
9	.248	.596	29.80	385,204	.240	.567	28.35	366,461	.228	.528	26.40	341,254	.222	.507	25.35	327,682
10	.248	.596	29.80	385,204	.260	.641	32.05	414,288	.227	.524	26.20	338,669	.222	.507	25.35	327,682
11	.248	.596	29.80	385,204	.244	.581	29.05	375,509	.227	.524	26.20	338,669	.222	.507	25.35	327,682
12	.248	.596	29.80	385,204	.241	.570	28.50	368,400	.227	.524	26.20	338,669	.222	.507	25.35	327,682
13	.248	.596	29.80	385,204	.240	.567	28.35	366,461	.227	.524	26.20	338,669	.222	.507	25.35	327,682
14	.247	.592	29.80	382,618	.239	.563	28.15	363,875	.227	.524	26.20	338,669	.222	.507	25.35	327,682
15	.246	.589	29.45	380,680	.238	.560	28.00	361,936	.227	.524	26.20	338,669	.222	.507	25.35	327,682
16	.246	.589	29.45	380,680	.236	.556	27.80	359,351	.227	.524	26.20	338,669	.221	.503	25.15	325,096
17	.245	.585	29.25	378,094	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.221	.503	25.15	325,096
18	.244	.581	29.05	375,509	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.221	.503	25.15	325,096
19	.243	.577	28.85	372,924	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.221	.503	25.15	325,096
20	.242	.574	28.70	370,985	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.220	.500	25.00	323,158
21	.240	.567	28.35	366,461	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.220	.500	25.00	323,158
22	.269	.671	33.55	433,677	.236	.556	27.80	359,351	.227	.524	26.20	338,669	.220	.500	25.00	323,158
23	.262	.647	32.35	418,166	.236	.556	27.80	359,351	.226	.520	26.00	336,084	.220	.500	25.00	323,158
24	.260	.641	32.05	414,288	.236	.556	27.80	359,351	.225	.517	25.85	334,145	.220	.500	25.00	323,158
25	.259	.637	31.85	411,703	.234	.549	27.45	354,827	.225	.517	25.85	334,145	.220	.500	25.00	323,158
26	.221	.503	25.15	325,096	.232	.542	27.10	350,303	.224	.514	25.70	332,206	.220	.500	25.00	323,158
27	.240	.567	28.35	366,461	.232	.542	27.10	350,303	.224	.514	25.70	332,206	.220	.500	25.00	323,158
28	.240	.567	28.35	366,461	.232	.542	27.10	350,303	.224	.514	25.70	332,206	.219	.496	24.80	320,572
29	.240	.567	28.35	366,461	.232	.542	27.10	350,303	.224	.514	25.70	332,206	.219	.496	24.80	320,572
30	.240	.567	28.35	366,461	.232	.542	27.10	350,303	.223	.510	25.50	329,621	.218	.493	24.65	318,633
31					.230	.535	26.75	345,779					.218	.493	24.65	318,633
Total				11,519,277				11,436,546				10,136,802				10,081,227
Average	.247	.594	29.70	383,976	.241	.571	28.55	368,921	.227	.523	26.15	337,893	.221	.503	25.15	325,201

TOTAL NEAR-BY SUPPLY.

Reviewing these measurements we have a probable summer minimum water supply available for the city from local sources approximately as follows:

Local water supply of Santa Barbara.

	Gals. per day.
Minimum from Mission Creek	100,000
Minimum from De la Guerra wells	300,000
Minimum from city tunnel	300,000
Total	700,000

as against an estimated normal summer demand of 1,200,000[a] gallons per day, or an estimated normal deficit daily of 500,000 gallons.

There is not as much water now being used in the city for beautifying lawns and gardens as would be so applied if a more abundant supply were available. From the above it is evident that the city should take immediate steps toward increasing its water supply.

DISTANT SUPPLIES.

EXTENSION OF CITY TUNNEL.

With a view to the extension of the present city tunnel through the Santa Ynez Range to tap the waters of Santa Ynez River, a system of triangulation was carried across the mountains from Santa Barbara to the Mono reservoir site by Homer Hamlin and W. B. Clapp, of the Geological Survey. The base line of this system was measured on State street, Santa Barbara, between Boulevard and Pedregosa streets, and the most northerly point was the high peaks south of the Mono reservoir site. The base line, which was carefully measured with a 300-foot steel tape under a uniform tension of 25 pounds and corrected for temperature, was 9,753.7 feet long. The angles were measured with a Berger transit No. 1b, circles 6¼ inches in diameter. Eleven principal triangulation stations and 5 secondary stations were occupied, the secondary triangulation being necessary to reach the south portal of the present city tunnel, which is situated in a deep canyon. Angles were repeated three times and measured in six sets of two each. The triangles closed for angles within 0° 0′ 0″ to 0° 0′ 10″. The angle adjustments were made by distributing the difference proportionally as probable error due to weather conditions. The traverse of the outside boundary of the triangulation system closed as follows: N., 45,343.66; S., 45,343.63; E., 28,397.22; W., 28,397.15.

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[a] On basis of 150 gallons per day for 8,000 persons.

The north portal of the extended tunnel, as projected, was fixed by a station on the cliff on the south side of Santa Ynez River. The north portal bears N. 26° 38′ 18″ E., and is 18,842.06 feet distant from the south portal of the present city tunnel. This tunnel was 4,895 feet long on January 26, and if an angle is made in it at 5,960 feet it will be necessary to drive 15,006 feet to reach Santa Ynez River and finish the work. By doing so a saving of 1,475 feet will be made; otherwise the tunnel must have a length of 21,376 feet to get through the range. It is probable, however, that a still more favorable location may be found.

From the surveys that have been made during the last season in the drainage basin of Santa Ynez River, the elevation of the south portal of the city tunnel in Cold Spring Canyon was taken at 1,393.06 feet; the rise on grade from the portal to station 48, at the projected north portal, is 49.02 feet. The total length of excavation necessary to complete this tunnel through the range is 15,066 feet. At a grade of 0.1 per cent this will require 15 feet more to be consumed in tunnel grade, making the elevation of the north portal of the tunnel 1,457.18 feet. The elevation of Santa Ynez River bed opposite is 1,425 feet. The necessary grade to be consumed from the north portal of the tunnel to the Mono reservoir site would be about 4 feet, making the elevation of the grade at the Mono reservoir site 1,461.18 feet. The elevation of the bed of the creek at the Mono site is 1,440 feet, so that the conduit grade would be 21.18 feet above the bed of the creek at that point, but the capacity of the lower portion of a reservoir site is always very small, and there would be a loss of but 1 per cent in the capacity of a 100-foot dam at the Mono with the elevations given.

CONSTRUCTION OF NEW TUNNEL.

In the old city tunnel in Cold Spring Canyon several angles occur in the alignment. The grade of the tunnel is also not satisfactory, in that it is too high to reach the bed of the stream at the mouth of the Mono at the elevation of the creek. While the old city tunnel could be used in this regard, it is not considered the best site for a tunnel, in view of subsequent surveys and investigations. Moreover, the old tunnel is delivering a very substantial water supply under existing conditions, particularly since being regulated by the bulkhead described above, and as a new tunnel can be obtained at a satisfactory elevation, which will develop a new water supply and in addition command certain reservoir sites on lower portions of the stream below the mouth of the Mono, it is desirable to adopt the second location. After the first investigations made in the basin of Santa Ynez River, which included the survey of the Mono reservoir site, the Main River reservoir site, and an inspection of sites higher on the stream, a much better site situated on the main stream below the mouth of the Mono was found. This is called the Gibraltar reservoir site and is described more fully below.

The capacity of the Gibraltar reservoir so not quite so great as that of the Mono, but is very satisfactory, while the dam site is very much better, and the tributary drainage area a great deal larger, including not only that of the Mono, but also that of the Santa Ynez above the Mono, and 17 square miles of Main Canyon below. For the season of 1902–3 the measured flow at the Mono dam site was 8,934 acre-feet, at the Santa Ynez above the Mono 9,898 acre-feet, and for the Santa Ynez at the Gibraltar reservoir site 21,202 acre-feet. As the water supply is the most essential feature of the entire enterprise, no hesitation is felt in recommending that the tunnel line which is to be run through the range should be made to command the Gibraltar reservoir site. This would be impossible with the old city tunnel, on account of its high elevation in Cold Spring Canyon. Moreover, the combined cost of the Gibraltar dam and of a tunnel to it from Mission Canyon is less than the combined cost for completing the old city tunnel and building the Mono dam.

For the reasons given above, the triangulation which had been made for the old city tunnel was extended so as to cover the site of a possible new tunnel line from Mission Canyon to the Gibraltar dam site, which would be 19,560 feet long and would run through the same general formation at right angles to the line of the strike of the rock, passing under portions of Mission Creek.

AGREEMENT WITH WATER COMPANY.

An agreement was made with the Santa Barbara Water Company for rights of way for this new tunnel line. This company has for years been acquiring lands along Mission Canyon in order to protect its water supply, which comes mostly therefrom. The company naturally felt that the running of the tunnel beneath Mission Creek might affect its supply of water from the creek and insisted on being secured against such a contingency. In consequence the Santa Barbara water commissioners entered into a contract with the company, by which the city agrees to maintain the supply of the company at 14 inches from July 1 to December 31 and at 22 inches from January 1 to June 30, supplying the water from the tunnel in case it is not flowing naturally in the creek, provided that amount can be supplied from the tunnel alone and irrespective of water subsequently obtained from storage reservoirs. In return the Santa Barbara Water Company gives the city rights of way over all its lands for wagon roads, tunnels, pipe lines, etc., and agrees not to run any tunnels on its lands in the vicinity of the city tunnel. This contract is fully justified by the physical conditions encountered in the water development. Moreover, the water delivered to the water company will be used in any event in the immediate vicinity of Santa Barbara or for the beautifying and improvement of the town.

A section of the proposed new tunnel is shown in figs. 16 and 17 (pp. 91, 92), the timbered section being used only where necessary and the rock section being the prevailing type for the tunnel.

CONTRACT FOR CONSTRUCTION.

The work of driving the tunnel was divided into two parts, a southern portion of the tunnel to be 11,000 feet long and constructed from the south portal, and a northern portion to be 8,560 feet long and constructed from the north portal. Bids were called for and received, and the contracts awarded to F. J. Smith and E. J. Hunt, of Santa Barbara, for the south part, and to Robert Beyrle, of Los Angeles, for the north part. The prices were as follows:

Successful bids for new Santa Barbara tunnel.

	South division.	North division.
Per cubic yard of excavation	$8.00	$9.00
Overhaul per cubic yard per 100 feet (free haul being 500 feet)	.02	.01½
Timbers in place (per M feet, B. M.)	35.00	45.00

The total cost of the southern portion of the tunnel under the contract will be $109,125, and for the northern portion $90,267, a total of $199,392 for the entire tunnel. The estimate of the author, as consulting engineer for the work, was 19,560 feet of tunnel at $10 a foot, $195,600, plus 10 per cent for contingencies, or a total of $215,160. An additional allowance was made of 5 per cent for engineering expenses.

The yardage excavated in the tunnel is to be limited by the quantity shown on the section. After the completion of the work the contractor is required to leave his track in the tunnel for the purpose of hauling cement through it for the construction of the dam on Santa Ynez River, thus avoiding a wagon haul over the high mountains. The contracts were let in February, 1904.

VENTURA RIVER.

From an examination of the topographic maps of the Geological Survey, which have been recently prepared and which are of inestimable value in a general consideration of this subject, it was found that it would be possible by a gravity line to divert the headwaters of Ventura River from a point near the junction of the main and north forks of Matilija Creek by gravity through Casitas Pass to Santa Barbara. A reconnaissance was made of this country, and a number of water measurements were made throughout the length of Ventura River. A month of minimum flow was selected as the proper time at which to make these determinations, as the minimum is the controlling condition in all questions involving water supply. There was a rainfall at Santa Barbara for the seasons of 1901-1902 of 14.06 inches. The stream flow during this season, however, was below normal.

TABLE 9.—*Flow measurements on Ventura River and tributaries.*

1902.	Locality.	Inches.
Sept. 25	At Matilija, above North Fork	99
25	North Fork at mouth	21
	Total, all diverted	120
25	River bed dry from Matilija School to near Coyote Creek	
25	Below Coyote Creek and below Domestic diversion	14
25	Head Domestic system's lower ditch	185
25	Head Domestic system's upper ditch	62
	Total Ventura River below and near Coyote Creek	261
26	Head of power ditch, below Domestic diversions	75
26	River bed above and near power house	8
	Total	83
26	Domestic ditch above and near reservoir	222

WATER AVAILABLE.

It will be noted that all of the water of Matilija Creek at the point from which a gravity line could be started to Santa Barbara is diverted and now in use, and consequently there was on that date no supply available for Santa Barbara at this point. In addition to this, the intervening topography is rugged and the distance would be very great, rendering it impracticable from a commercial standpoint to obtain a supply from this source.

It will also be noted that there were 75 inches of water diverted into the power ditch of the Ventura waterworks, which runs from a point approximately 4 miles north of Ventura to a point approximately 1½ miles north of this city, and that there were 8 inches of water above the point where this power ditch would discharge into the river, making a total of 83 inches in the lower portion of the river that was not diverted for domestic uses. During the daytime, at the time of the inspection, all this 75 inches of water was being used for irrigation, leaving but 8 inches of water in Ventura River available for surface diversion. Information, however, was given that a portion of the water diverted through the domestic conduits during the daytime is accumulated in a certain domestic reservoir, and that at nighttime, from 11 p. m. until 6 a. m., a discharge of 280 miner's inches from this reservoir ordinarily takes place through the power house for the purpose of developing power and is wasted into the river. This is equivalent to a continuous flow of 82 miner's inches. This water wasted into the sea, taken in connection with the 8 inches flowing in the stream bed above the power house, makes a total of 90 miner's inches of water, which at this time, admitted to be one of drought, might be considered as wasted water and available for sale or disposal by the Ventura Water, Light, and Power Company. In addition to this, it is stated that the 75 inches of water diverted through the power ditch is not permanently sold for irrigation purposes, but is used by irrigators by sufferance on the part of the water company, and that the Ventura Water, Light, and Power Company could sell it to the city of Santa Barbara if it so desired. There thus might be made available from the lower portion of Ventura River a low-water supply of 165 miner's inches (2,145,000 gallons per day), provided all the above assumptions are correct.

The statement was made that there is practically a continuous use of the 30 inches of water from the power ditch during the daytime for irrigation, which might reduce these figures to 135 miner's inches (1,750,000 gallons daily). This is an unusually large amount of water to be available for disposal along this coast, and it was considered to be sufficient to justify a further investigation to determine the cost of its delivery to Santa Barbara.

The elevation at which this water could be obtained is practically 50 feet above sea level, and it would, therefore, have to be pumped to Santa Barbara through a long force main, laid possibly on the railroad right of way, for an aggregate distance of 26.2 miles. There is quite favorable opportunity of obtaining cheap fuel along this line, and a pumping station might be erected at the intake and a sufficient head generated to force the water through the pipe line, delivering it to the city of Santa Barbara at the foot of State street without pressure, in order to avoid the expense of a long pipe line designed to withstand high heads. At this point it would be picked up by a second pumping plant and forced to the high levels of the city. No legal examination of title was made as to the ownership of this water.

COST OF PIPING AND PUMPING.

It may be assumed, therefore, for the sake of estimating, that there is available from the lower Ventura River a supply of water sufficient to furnish 1,500,000 gallons daily, adequate for 10,000 people using 150 gallons per capita each day. This is equal to 2.32 cubic feet per second, or 116 miner's inches of water. This water would have to be purchased from the Ventura Water, Light, and Power Company, from which no figure has as yet been obtained as to the price for which it would be sold. It is believed that the parties owning this water would be willing to contract for its delivery. If $300 per miner's inch were paid for this water, it would cost the city of Santa Barbara $34,800 at Ventura. An 18-inch continuous wooden stave pipe laid from the Ventura River to the foot of State street would be 138,300 feet in length, or 26.2 miles. The friction head to be overcome by water passing through this length of pipe, when carrying 1,500,000 gallons daily, would be 48.4 feet. It is believed that the average friction and hydraulic head on the pipe would be 50 feet. The pipe would be laid either on country roads or possibly along the railroad right of way. At certain projecting and precipitous cliffs the pipe would have to be run through tunnels. The conduit would be what is technically known as a continuous wooden stave pipe with steel bands, a form of construction which is satisfactory. It would be of a more permanent character than riveted pipe, but not of so enduring a nature as cast-iron pipe. Cast-iron pipe, however, because of its present high cost ($45 a ton delivered at Pacific coast terminals), would be entirely out of the question. The water would be delivered without pressure at the foot of State street, in order to avoid excessive cost due to necessarily stronger pipe required in case a high head was put on it to directly connect with the mains of the city for local distribution. From this point it would have to be lifted to domestic reservoirs. The following table is an estimate on the cost of laying such a pipe line:

TABLE 10.—*Estimated cost of Santa Barbara-Ventura pipe line.*

Section.	Length.	Class of excavation.	Cost.	Cost of excavation.	Cost of backfill.	Total cost of trenching.	Cost of pipe.	Total cost.
	Lin. ft.		*Lin. ft.*					
1	7,920	Trench	$0.15274	$1,209.70	$302.42	$1,512.12	$9,504.00	$11,016.12
2	6,864	do.	.191	1,311.02	327.75	1,638.77	8,236.80	9,875.57
3	2,640	do.	.15274	403.23	100.81	504.04	3,168.00	3,672.04
4	1,584	do.	.09546	151.21	37.80	189.01	1,900.80	2,089.81
5	1,320	Tunnel	5.00	6,600.00	....	6,600.00	1,584.00	8,184.00
6	27,984	Trench	.09546	2,671 35	667.84	3,339.19	33,580.80	36,919.99
7	6,072	Tunnel	5.00	30,360.00	....	30,360.00	7,286.40	37,646.40
8	7,392	Trench	.09546	705.64	176.41	882.05	8,870.40	9,752.45
9	5,280	Tunnel	5.00	26,400.00	....	26,400.00	6,336.00	32,736.00
10	9,500	Trench	.17183	1,632.38	408.10	2,040.48	11,400.00	13,440.48
11	61,776	do.	.09546	5,897.14	1,474.28	7,371.42	74,131.20	81,502.62
Total	138,332	....	....	77,341.67	3,495.41	80,837.08	165,998.40	246,835.48

A portion of the line would be in ground that is quite alkaline. The wooden part of the pipe would not be attacked by the alkali, but the iron rods would be. If we assume a length of life for the pipe of twenty years, and that a sinking fund at 4 per cent interest would necessarily have to be provided to renew it at the end of that time, $8,287.54 would have to be set aside annually to meet the charge. At 4 per cent interest this would capitalize at $207,188, which should properly be added to the first cost of the pipe, giving $454,023 as the real cost of the pipe line to the city. This computation is given in order to compare the real cost of this pipe line with other permanent construction mentioned later.

It would be necessary to install two pumping plants, one at Ventura to force this water through the pipe line against the friction head, and the other to lift the water from the foot of State street to an assumed level of 300 feet to a domestic reservoir. The cost of the first plant would be $9,649, and of the second plant $13,970, or a total of $23,619. If a life of twenty years is assumed for pumping plants also, and provision is made for their renewal by a sinking fund as before, bearing 4 per cent interest, there would have to be set aside each year for this purpose $792.49, which is interest at 4 per cent on $19,802, making a total cost to the city of pumping plants of $43,421.

These pumping plants would be improved and modern triple-expansion condensing steam plants. The first plant would consume 5.5 barrels of crude oil daily, and the second 14.5 barrels of oil daily, or a total of 20 barrels of oil daily to deliver 1½ million gallons daily. This oil at $1 a barrel, which would be a fair price for a long period of use, would represent a daily charge of $20, and an annual charge of $7,300. Attendance of engineers and assistants would probably amount to $5,000 annually; so the oil and attendance together would be $12,300, which, capitalized at 4 per cent, represents $307,500.

To summarize we now have:

Summary of cost of Santa Barbara-Ventura pipe line.

	First cost.	First cost and maintenance.
1,500,000 gallons of water daily	$34,800	$34,800
Pipe line	246,835	454,023
Two pumping plants	23,619	43,421
Fuel and attendance	....	307,500
Total	305,254	839,744

This figure of first cost and maintenance would represent the real expense to the city of building and maintaining such a plant perpetually, and on this basis can be properly compared with permanent construction, such as masonry.

This plant would practically be incapable of being increased in capacity without rebuilding the entire system, and no estimates have been included for rights of way.

SANTA YNEZ RIVER.

The county of Santa Barbara, by petition of its board of supervisors, and the city, through its trustees, requested the United States Geological Survey to make topographic surveys and hydrographic investigations in Santa Barbara County to assist in the solution of the difficult water problems which confront this beautiful coast district, often called the American Riviera. As it is the policy of the Geological Survey to carry on its work where the results will be of greatest value, it acceded to this request and has extended its topographic surveys over the greater portion of the county. Pl. I is made up from the results of these surveys. Hydraulic investigations have also been begun, three reservoirs surveyed, several tunnel lines triangulated, and three gaging stations established. It is intended to extend these investigations during the coming season so as to cover the entire drainage basin of Santa Ynez River. To a limited extent the city of Santa Barbara has cooperated financially in the hydraulic work.

Santa Ynez River rises in the mountains of Santa Barbara and Ventura counties, and flows westerly with a flat grade to the Pacific Ocean, having a length of approximately 75 miles. The Santa Ynez Range of mountains, varying in elevation from 3,000 to 4,000 feet, forms the southern boundary of this drainage basin. The northern divide ranges from 4,500 to 5,500 feet, culminating in Mount Pinos, the elevation of which is 8,826 feet. The mean elevation of the basin above the mouth of Mono Creek is 3,500 feet above sea level.

RAINFALL.

The mean rainfall at Santa Barbara is 16.78 inches; at Nordhoff, in Ventura County, at an elevation of 1,200 feet, it is about 18 inches; at Mutau Flat, on the headwaters of Piru Creek, and on the eastern slope of the range, at an elevation of 4,850 feet, it is 19 inches; at Snedden's ranch, on the north fork of the headwaters of the Piru, on the eastern slope of the mountains, at an elevation of 4,900 feet, it is 15 inches; at Cuddy's ranch, at an elevation of 5,000 feet, in Kern County, near the head of Tejon Creek, it is 20 inches, and at Old Fort Tejon, at an elevation of 3,245 feet, it is 18 inches. These records, except those of Santa Barbara, which were begun in 1867, are of rather short duration and fragmentary. The mean rainfall given for each mountain station is determined by finding the ratio of precipitation at Santa

Barbara for the years during which rainfall was observed at the high point in question, and the mean of the 37-year record at Santa Barbara, and applying that ratio to the observed rainfall at the mountain station. There are no known observations of rainfall in the upper portion of the Santa Ynez.

It is well known by the people living along the Pacific coast that the rainfall increases as the slope of the mountain ranges exposed to the sea breezes is ascended. Usually this increase amounts to six-tenths of an inch of rain for each 100 feet rise in elevation, which increase is to be added to the observed precipitation at the base of the range. On the eastern slope of the mountain ranges, on the side away from the ocean, this estimate does not at all hold, there being an actual diminution of rainfall after passing a crest. Consequently it is to be expected that such stations as Mutau Flat and Snedden's ranch, situated easterly from the main crest of the Coast Range, will have less precipitation than occurs on the exposed westerly side of the range. The Santa Ynez Range undoubtedly abstracts a portion of the moisture of the clouds that are passing inland over the drainage basin of Santa Ynez River, but the precipitation must again increase on the westerly sides of the high Coast Range on the northerly and easterly portions of the drainage basin, where the mountains rise from 2,000 to 3,000 feet higher than the summits of the Santa Ynez Mountains.

Mr. Purslow says that the rainfall in the basin of the Santa Ynez above the reservoir sites which he examined is 30 inches, and Mr. Wright states that in his judgment it is over 20 inches. Mr. Marsden Manson, civil engineer of the California Water and Forest Association, prepared a rainfall map, showing precipitation throughout the State, on which he estimates the rainfall in this district as between 20 and 30 inches. Mr. William Hammond Hall, when State engineer of California, also prepared a rainfall map, showing the precipitation for this district to be between 20 and 30 inches. Lieutenant Glassford, of the United States Signal Service, in 1891 officially estimated the rainfall on the headwaters of the Santa Ynez at from 20 to 25 inches.

After a careful examination of the drainage basin, of the vegetation covering it, of available rainfall records, and from a general knowledge of the precipitation throughout this portion of the State, the writer believes that the average rainfall in this basin is about 22 inches. However, in order to be within safe limits in making the estimates of available water supply, the same rainfall is used for computing the run-off of the Santa Ynez basin as has been observed at Santa Barbara.

RUN-OFF.

The question of determining the relation of what is called run-off (or the amount of water the streams discharge) to rainfall is one of considerable difficulty and uncertainty. It is dependent upon the character of the rains, whether gentle showers or violent storms (the latter yielding the greater run-off), and also upon the steepness of the slopes and the size of the watershed. Other things being equal, the small watershed has the higher percentage of run-off. A one or two years' record does not establish a final ratio.

The forest cover of the drainage basin also greatly affects the run-off. If it is a denuded area the floods are more violent and shorter in duration and the summer stream is much lower. If the drainage basin has a proper forest or brush cover the stream is more uniform in flow and carries less silt. The general porosity of the soil and rock also affects the character of the run-off.

A number of efforts have been made to establish this ratio of rainfall to run-off. The diagram presented herewith as fig. 1 (p. 15) shows by curved lines on a horizontal scale the amount of rainfall in inches of depth, and on the vertical scale the total corresponding volume of water discharged in acre-feet, an acre-foot of water being the amount that will cover 1 acre 1 foot deep, or 43,560 cubic feet. The curve which is used in this report is one that has been determined as the result of a large number of measurements in California made by the United States Geological Survey. It will be noted that it indicates less run-off than the others.

The Salt Springs Valley reservoir is in Calaveras County, Cal., in the foothills. The Newell curve for "mountainous areas" is a general determination, by Mr. F. H. Newell, hydrographer of the Geological Survey, for the high mountain areas of the western portions of the United States. The Arrowhead reservoir is in San Bernardino County, Cal. The Newell curve for "undulating areas" is the relation determined by Mr. Newell for hill countries. The general curve for large watersheds for California is the one used in this report as the result of California observations made largely during the drought period through which we have passed. It will be noted that there is no run-off indicated until after the rainfall exceeds 10 inches. All of these curves are much more unfavorable to large run-off than has customarily been accepted for eastern streams.

TABLE 11.—*Record of precipitation at Santa Barbara, Cal.*

[Latitude, 34° 25′; longitude, 119° 40′. Elevation, 100 feet. Authority, War Department and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1867–68	0.00	0.00	2.31	12.67	3.97	2.00	1.08	2.44	0.72	0.00	0.00	0.00	25.19
1868–69	.00	.00	1.25	4.26	3.26	2.12	4.22	.46	.20	.00	.00	.00	15.77
1869–70	.00	.30	.65	.57	.25	5.87	.83	.99	.74	.07	.00	.00	10.27
1870–71	.00	1.04	.27	1.41	.86	2.92	.02	2.02	.37	.00	.00	.00	8.91
1871–72	.00	.09	1.83	6.56	2.53	1.81	.18	1.80	.00	.14	.00	.02	14.96
1872–73	.05	.00	.00	4.34	.58	5.48	.05	.00	.00	.00	.00	.00	10.50
1873–74	.00	.00	.27	5.26	4.54	3.17	.78	.28	.14	.00	.00	.00	14.44
1874–75	.00	1.91	1.30	.00	14.84	.18	.38	.10	.00	.00	.00	.00	18.71
1875–76	.00	.00	6.53	.31	7.56	5.67	2.73	.27	.00	.00	.00	.00	23.07
1876–77	.00	.32	.00	.00	2.72	.00	.82	.18	.45	.00	.00	.00	4.49
1877–78	.00	.00	1.32	3.12	7.17	11.73	2.47	3.34	.29	.07	.00	.00	29.51
1878–79	.00	.32	.00	5.16	5.24	.71	.34	1.60	.21	.00	.00	.00	13.58
1879–80	.00	.41	1.62	4.57	1.30	10.86	1.15	5.73	.00	.00	.00	.00	25.64
1880–81	.00	.25	.28	9.73	2.83	.30	1.25	.59	.00	.00	.00	.00	15.23
1881–82	.44	1.47	.33	.95	1.13	2.38	5.74	1.63	.00	.20	.00	.00	14.27
1882–83	.00	.37	.77	.10	2.18	2.92	3.64	.29	2.79	.35	.00	.00	13.41
1883–84	.00	1.32	.00	2.76	6.33	9.68	9.77	2.60	.39	1.62	.00	.00	34.47
1884–85	.00	1.02	.79	6.62	1.23	.07	.35	3.00	.00	.00	.00	.00	13.08
1885–86	.00	.19	9.84	2.47	5.12	1.19	2.03	3.40	.00	.00	.00	.00	24.24
1886–87	.00	.39	.87	.86	.31	8.64	.13	1.43	.33	.03	.00	.00	12.99
1887–88	.38	.31	1.10	4.43	10.15	1.30	3.86	.16	.02	T.	T.	T.	21.71
1888–89	.03	.07	5.62	5.59	.29	1.29	7.31	.49	.76	.13	.00	.00	21.58
1889–90	.00	8.65	3.21	10.64	5.32	2.96	1.10	.31	.18	.00	.00	.00	32.37
1890–91	1.50	.00	.48	3.53	.50	8.82	1.65	1.90	.00	.00	.00	.00	18.38
1891–92	.18	.00	.00	2.26	1.04	2.48	3.36	.34	.62	.00	.00	.00	10.28
1892–93	.00	.42	3.70	7.31	4.52	3.55	7.53	.38	.00	.00	.00	.00	27.41
1893–94	.00	.62	T.	3.50	.65	.50	.22	.35	.86	.00	.15	.00	6.85
1894–95	1.36	.78	.11	4.16	6.25	.67	1.99	.46	.02	.05	T.	.00	15.85
1895–96	.00	.55	.77	.93	6.84	.00	2.37	1.78	.08	.05	.40	.00	13.77
1896–97	.00	.92	3.51	2.92	4.35	3.65	2.73	.02	.00	.00	.00	.00	18.10
1897–98	.00	1.44	.00	.00	.63	1.39	.28	T.	1.25	.00	T.	.00	4.99
1898–99	3.17	.14	.00	.36	4.48	.00	2.78	.64	.00	.78	.00	.00	12.35
1899–1900	.00	2.06	1.97	2.35	2.32	.05	1.58	.42	1.90	.01	.02	T.	12.68
1900–1901	.04	.15	3.99	.02	4.86	3.65	.16	2.07	.34	.10	.06	.09	15.53
1901–2	.36	2.42	1.16	T.	1.36	4.40	2.89	1.40	.07	.00	.00	.00	14.06
1902–3	.00	1.48	4.01	2.24	2.06	1.63	6.12	2.91	.00	.00	.00	.00	20.45
1903–4	T.	T.	.05	T.	.46	4.69	4.40	1.89	.09	.00	.00	.10	11.68
37-year mean.													16.78

As has been previously stated, the rainfall for the drainage basin of the Santa Ynez above the Mono, and for Mono Creek, is taken in the computations as 16.78 inches as an average, which is the rainfall observed for thirty-seven years at Santa Barbara.

The drainage area above the various reservoir sites was carefully determined from the topographic surveys of the Geological Survey which have been recently made. The area above the Juncal reservoir site is 13.4 square miles; above the Mono reservoir site, 119 square miles; above the Main River reservoir site, on the Santa Ynez just below the mouth of Blue Canyon, 71 square miles; above the Gibraltar reservoir site on the main river, 207 square miles.

The exposure of the drainage basin of the Santa Ynez proper is more favorable for a large amount of run-off than that of the Mono. The rainfall usually increases as the mountains rise in elevation, but the heaviest precipitation is generally just beyond the crest of the range of hills; consequently we would expect an unusually large precipitation just beyond the summit of the Santa Ynez Range north of Santa Barbara. Moreover, this exposure being a northern one, there is less loss by evaporation from the soil. This rainfall is strikingly indicated by the brush cover on the Santa Ynez Mountains as compared with the cover in the drainage basin of the Mono.

As an illustration, it may be mentioned that during the season of 1902-3 the Mono drainage basin discharged 8,934 acre-feet of water from 119 square miles; the Santa Ynez above the Mono discharged 9,898 acre-feet from 71 square miles, and the basin above the Gibraltar dam site discharged 21,202[a] acre-feet from 207 square miles.

By applying the diagram (fig. 1) showing the relation of rainfall to run-off to the drainage areas of each of the sites, the probable volume of water available at each in each year has been obtained and is given in the last three columns of table 12. It will be noted that there is a very great fluctuation in the volume discharged in various years. For instance, in 1875-76 there were probably 35,190 acre-feet of water discharged through the Gibraltar reservoir site; in the following year there were no flood discharges whatever; while in the year 1877-78 there were probably 66,240 acre-feet. This is a strong argument in favor of building reservoirs of sufficient capacity to hold over from years of abundance to years of deficiency. It would not be possible to catch and retain all the water in all of the years, as there is a limit to the height of dam that should be built to be commercially profitable.

In consulting a table of estimated discharge of stream flow for any given section, it must be borne in mind that the figures are purely hypothetical, exact determination being impossible, for numerous reasons. The character of the run-off is dependent upon the character of each particular rain storm, whether it is a gentle shower or violent downpour. Again, one storm quickly following another will produce a greater stream discharge, because there is less opportunity of absorption of the rain by the ground. The character of the exposure, forest cover, etc., all enter into the considerations, rendering the question one of great intricacy. The table given is based upon general results obtained in southern California and must be considered merely as an estimate made from the most reliable data in hand. In order to obtain intelligent results along these lines, it is exceedingly important for the city of Santa Barbara to maintain gagings on Santa Ynez River continuously, particularly during the construction of the tunnel prior to the building of the dam at Gibraltar.

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[a] Estimated.

TABLE 12.—*Hypothetical run-off for Santa Ynez reservoir sites on basis of observed Santa Barbara rainfall and run-off diagram.*

Year.	Rainfall of Santa Barbara and Santa Ynez.	Run-off per square mile in acre-feet.	Total run-off in acre-feet.			
			Juncal (drainage area, 13 square miles).	Mono (drainage area, 119 square miles).	Main river (drainage area, 71 square miles).	Gibraltar (drainage area, 207 square miles).
1867–68	25.19	210	2,730	24,990	14,910	43,470
1868–69	15.77	60	780	7,140	4,260	12,420
1869–70	10.27					
1870–71	8.91					
1871–72	14.96	50	650	5,950	3,550	10,350
1872–73	10.50					
1873–74	14.44	40	520	4,760	2,840	8,280
1874–75	18.71	105	1,365	12,495	7,455	21,735
1875–76	23.07	170	2,210	20,230	12,070	35,190
1876–77	4.49					
1877–78	29.51	320	4,160	38,080	22,720	66,240
1878–79	13.58	40	520	4,760	2,840	8,280
1879–80	25.64	230	2,990	27,370	16,330	47,610
1880–81	15.25	50	650	5,950	3,550	10,350
1881–82	14.27	40	520	4,760	2,840	8,280
1882–83	13.41	30	390	3,570	2,130	6,210
1883–84	34.47	430	5,590	51,170	30,530	89,010
1884–85	13.08	30	390	3,570	2,130	6,210
1885–86	24.24	190	2,470	22,610	13,490	39,330
1886–87	12.99	30	390	3,570	2,130	6,210
1887–88	21.71	150	1,950	17,850	10,650	31,050
1888–89	21.58	150	1,950	17,850	10,650	31,050
1889–90	32.37	370	4,810	44,030	26,270	76,590
1890–91	18.38	90	1,170	10,710	6,390	18,630
1891–92	10.28					
1892–93	27.41	255	3,315	30,345	18,105	52,785
1893–94	6.85					
1894–95	15.83	60	780	7,140	4,260	12,420
1895–96	13.77	40	520	4,760	2,840	8,280
1896–97	18.10	90	1,170	10,710	6,390	18,630
1897–98	4.99					
1898–99	12.35	20	260	2,380	1,420	4,140
1899–1900	12.68	30	390	3,570	2,130	6,210
1900–1901	15.53	60	780	7,140	4,260	12,420
1901–2	14.06	40	520	4,760	2,840	8,280
1902–3	20.45	120	1,560	[a]14,280	[b]8,520	24,840
1903–4	11.68	15	195	1,785	1,065	3,105

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[a] Measured flow, 8,934 acre-feet.

[b] Measured flow, 9,898 acre-feet.

TABLE 13.—*Measured run-off of Santa Ynez River and Mono Creek for 1902–3.*

Month.	Total run-off in acre-feet.	
	Mono at dam site (drainage area, 119 square miles).	Main river above Mono (drainage area, 71 square miles).
1902.		
July	0	0
August	0	0
September	0	0
October	0	0
November	173	280
December	12	111
1903.		
January	676	1,193
February	389	755
March	1,845	1,230
April	4,820	4,998
May	799	1,045
June	220	286
	8,934	9,898
Estimate for 1902–3	14,280	8,520
Run-off for 1902–3, in acre-feet per square mile	75.1	139.4
1903.		
July	21	68
August	10	31
September	7	18
October	3	9
November	2	[a] 12
December	3	[a] 14
	46	152

[a] Estimated.

Run-off at Gibraltar, in acre-feet, for 1902–3.

[Estimated.]

Mono at dam site	8,934
Santa Ynez above Mono	9,898
17 square miles below Mono, estimated (17 × 139.4)	2,370
Total for Gibraltar	21,202

Total run-off, in acre-feet, of main river at Gibraltar dam site.

[Drainage area, 207 square miles.]

1903.[a]		1904.	
July	0	July	2
August	0	August	0
September	0	September	11,484
October	0	October	535
November	0	November	381
December	17	December	430
1904.		1905.	
January (7–31)	45	January	4,538
February	690	February	39,753
March	1,857		
April	1,125		
May	418		
June	42		
Total for season	4,194		

It is suggested that a reservoir should be so constructed as to supply at least 150 gallons per capita daily for a population of 10,000, the use and evaporation in this case amounting to about 2,100 acre-feet yearly. At the Mono reservoir site a dam 85 feet high, holding water to a maximum depth at the dam of 75 feet, would give this continuous supply for nineteen months. At the Gibraltar reservoir site a dam 100 feet high would impound a two years' supply, and a dam 155 feet high would have a capacity of 15,793 acre-feet. These figures as to flow of the streams and capacities of reservoirs indicate the adequacy of a system based upon these physical conditions. The records of stream flow should be continuously maintained to assist in the determination of the requisite height of dam.

QUALITY OF WATER.

The quality of the water in the neighborhood of Santa Barbara has been made the subject of long study by Prof. James A. Dodge, of Santa Barbara. Herewith are given certain analyses made by him of the water of creeks in this vicinity. Although these are not absolutely complete, inasmuch as small quantities of minerals present are not stated, they were made with care. Other complete analyses that were made subsequently show no material difference from the results given. The analysis of the water of the city tunnel as supplied to consumers in Santa Barbara was made at the request of Doctor Cassal, health officer in 1899. The amount of mineral substances in solution in the tunnel water does not materially differ from that shown by the analysis made of Mission Creek waters in 1894. Other analyses made by Professor Dodge at various times, of waters from the wells in the city, show them to be, generally speaking, very similar to the creek water. Professor Dodge concludes that the ordinary water in use for domestic purposes from the strip of country between Santa Ynez Mountains and the ocean is practically uniform in quality. There are, however, exceptional waters in this vicinity differing decidedly from those above referred to, one of these being the Veronica water, and another the water from the Hot Springs.

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[a] Estimated.

ANALYSES OF SAMPLES.

Certain analyses were made of the water from Mono Creek by Prof. Laird J. Stabler, chemist for the University of Southern California and also for the Southern California Medical College, one (No. 5) being of the low summer flow, consisting of merely a few miner's inches seeping through the sands and gravels and naturally containing an abnormally large amount of mineral matter. Another (No. 7) was of the water from the first floods from the drainage basin, which, as is customary after a long drought, carried some of the accumulated salts deposited along the margins of the stream by summer evaporation, and also a large amount of pulverized sediment trampled by stock during the preceding summer and readily picked up and carried away by the first dash of water over the ground. These analyses of the low-water stage at the end of a dry season and the first flood water are the most unfavorable that could be made. The analyses of the later floods, made as the season advanced, give smaller amounts both of silt and of mineral matter, as shown in analyses No. 9 and No. 12.

Analysis No. 1, water of Mission Creek.

[Analyst, James A. Dodge; date of analysis, June, 1894.]

	Grains per U. S. gallon.
Sodium chloride	1.28
Sodium sulphate	6.95
Calcium sulphate	7.45
Calcium carbonate	6.02
Magnesium carbonate	4.21
Potassium carbonate	Trace.
Alumina and iron salts	Trace.
Silica	Trace.
Total	25.91

Reaction of residue left by evaporation in a platinum dish, slightly alkaline.

Analysis No. 2, water of Cold Spring Creek.

[Analyst, James A. Dodge; date of analysis, June, 1894.]

	Grains per U. S. gallon.
Sodium chloride	1.05
Sodium sulphate	5.96
Calcium sulphate	10.63

	Grains per U. S. gallon.
Calcium carbonate	6.25
Magnesium carbonate	6.54
Potassium carbonate	Trace.
Alumina and iron salts	Trace.
Silica	Trace.
Total	30.43

Reaction of residue left by evaporation in a platinum dish, slightly alkaline.

Analysis No. 3, water from the Santa Barbara city water tunnel.

[Analyst, James A. Dodge; analysis made in November, 1899, for Doctor Cassal, health officer.]

	Grains per U. S. gallon.
Sodium chloride	0.537
Sodium sulphate	8.392
Magnesium sulphate	3.118
Magnesium carbonate	1.769
Calcium carbonate	14.097
Iron carbonate	.122
Potassium carbonate	.379
Lithium salts	Trace.
Silica	Trace.
Nitrates	Trace.
Organic carbonaceous matter	Trace.
Total	28.414

Analysis No. 4, water from Santa Ynez River at gaging station one-half mile above mouth of Mono Creek.

[Collected by S. G. Bennett, January 4, 1903; analyst, Laird J. Stabler. Clear water; low stage before winter floods.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	2.72	4.68
Sodium sulphate	29.82	51.19
Sodium carbonate	16.57	28.41
Total solids	42.91	73.60

Analysis No. 5, water from Mono Creek at gaging station near mouth.

[Collected by S. G. Bennett, January 4, 1903; analyst, Laird J. Stabler. Clear water, low stage.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	5.94	10.20
Sodium sulphate	58.28	99.94
Sodium carbonate	17.94	30.74
Total mineral matter	81.64	140.00

Analysis No. 6, water from Santa Ynez River above mouth of Mono Creek.

[Collected by W. B. Clapp, November, 1902; analyst, Laird J. Stabler. First flood.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	2.50	3.5
Sodium sulphate	38.25	65.6
Sodium carbonate	10.13	17.38
Total solids in suspension	1,749.50	2,640.00
Total solids in solution	67.64	116.00

Solid matter deposited in 30 hours, 7.3 per cent by volume; solid matter deposited in 3 days, 7.3 per cent by volume.

Analysis No. 7, water from Mono Creek near dam site.

[Collected by W. B. Clapp, November, 1902; analyst, Laird J. Stabler. First flood.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	2.3	3.94
Sodium sulphate	33.11	56.80
Sodium carbonate	9.51	16.32
Total solids in suspension	342.80	931.00
Total solids in solution	57.15	98.00

Solid matter deposited in 30 hours, 4 per cent by volume; solid matter deposited in 3 days, 4.1 per cent by volume.

Andlysis No. 7, water from Mono Creek.

[Collected January 24, 1903, at low stage; analyst, James A. Dodge.]

	Grains per gallon.
Suspended siliceous matter, separated by filtration	1.46
Sodium chloride	5.49
Sodium carbonate	3.73
Sodium sulphate	13.14
Magnesium sulphate	22.43
Calcium sulphate	10.34
Calcium carbonate	16.99
Aluminum sulphate	1.17
Iron salts	Trace.
Potassium salts	Trace.
Organic matter	Trace.
Total dissolved substances:	73.29

The following analyses of waters from Mono Creek and Santa Ynez River were taken from the low stage of the stream subsequent to the first flood, but it is believed that they still contained abnormally high quantities of solids in solution:

Analysis No. 8, water from Santa Ynez River at cable station.

[Collected by H. Rankin, January 29, 1903; analyst, Laird J. Stabler. Low stage.]

	Grains per gallon.	Parts per 100,000.
Chlorides as sodium chloride	2.04	3.5
Carbonates as sodium carbonate	14.45	24.8
Sulphates as sodium sulphate	18.49	31.72
Total solids in solution	34.99	60.00
Total solids in suspension (0.02 per cent)	11.66	20.00

Analysis No. 9, water from Mono Creek at cable station.

[Collected by H. Rankin, January 29, 1903; analyst, L. J. Stabler.]

	Grains per gallon	Parts per 100,000.
Chlorides as sodium chloride	3.67	6.3
Carbonates as sodium carbonate	10.99	18.86
Sulphates as sodium sulphate	37.00	63.44
Total solids in suspension (0.02 per cent)	13.99	24.00
Total solids in solution	56.20	97.2

Analysis No. 10, water from Santa Ynez River at cable station.

[Collected by H. Rankin, January 30, 1903; analyst, L. J. Stabler.]

	Grains per gallon.	Parts per 100,000.
Chlorides as sodium chloride	2.04	3.5
Carbonates as sodium carbonate	16.31	27.98
Sulphates as sodium sulphate	18.64	31.96
Solids in solution	44.51	69.2

Analysis No. 11, water from Mono Creek at cable station.

[Collected by H. Rankin, January 30, 1903; analyst, L. J. Stabler.]

	Grains per gallon.	Parts per 100,000.
Chlorides as sodium chloride	3.67	6.3
Carbonates as sodium carbonate	14.60	25.01
Sulphates as sodium sulphate	44.10	75.64
Solids in solution	65.42	112.0

Analysis No. 12, water from Mono Creek.

[Collected by H. Rankin, January 28, 1903; analyst, James A. Dodge. Flood water.]

	Grains per gallon.
Sodium chloride	0.99
Sodium carbonate	1.05
Sodium sulphate	7.59
Magnesium sulphate	3.52
Calcium sulphate	6.07
Calcium carbonate	7.83
Iron carbonate	.88
Potassium salts	Trace.
Organic matter	Trace.
Total	27.93

This water contained silt, suspended and subsided, consisting mainly of clay, but containing some fragments of vegetable matter, and amounting to 3½ per cent by weight of the total water. This silt subsided with moderate quickness and left the water clear in somewhat less than three days.

Analysis No. 13, water from Mono Creek.

[Collected by H. Rankin, February 26, 1903; discharge, 4.50 second-feet; analyst, L. J. Stabler.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	4.01	6.87
Sodium carbonate	2.00	3.43
Sodium sulphate	14.85	25.46
Potassium sulphate	1.02	1.72
Calcium sulphate	30.45	52.22
Calcium carbonate	3.82	6.56
Magnesium carbonate	8.42	14.43
Total	64.57	110.69

The mineral matter is rather excessive for domestic purposes. The alkali salts are not beyond the limit for irrigation, but amount present would be large for some soils. The water would form considerable hard scale in boilers. As this is a low-water sample, it shows more mineral salts than flood-water samples.

Analysis No. 14, water from Mono Creek.

[Collected by H. Rankin, February 26, 1903; discharge, 4.5 second-feet; analyst, James A. Dodge.]

	Grains per gallon
Sodium chloride	3.97
Sodium carbonate	3.91
Sodium sulphate	13.84
Magnesium sulphate	21.55
Calcium sulphate	8.37
Calcium carbonate	22.02
Iron carbonate	Trace.
Aluminum sulphate	0.52
Potassium salts	Trace.
Silica	0.41
Total	74.59
Suspended matter	0.29

Analysis No. 15, from Santa Ynez River at Gibraltar.

[Collected by L. M. Hyde, May 2, 1904; discharge, 16.97 second-feet; analyst, James A. Dodge.]

1. General character of the water.

Clear, colorless, free from odor, of good taste; showing a slight sediment in the bottle, not sufficient for quantitative determination. Reaction slightly alkaline.

2. Organic matter.

A microscopic examination of the very small amount of matter separated by filtering, including the above-mentioned sediment, showed some plant fibers and parts of vegetable organisms; also a few infusoria in a state of activity. These are usually present in river and lake waters.

3. Chemical analysis of the mineral matter in solution.

	Parts per 100,000.	Grains per U. S. gallon.
Calcium carbonate	34.98	20.393
Calcium sulphate	4.03	2.350
Magnesium sulphate	25.78	15.030
Sodium sulphate	12.57	7.328
Sodium chloride	3.64	2.122
Potassium carbonate	1.05	0.612
Lithium salts	Trace.	Trace.
Iron salts	Trace.	Trace.
Nitrates	Trace.	Trace.
Silica	Trace.	Trace.
Total	82.05	47.835

The foregoing substances are to be understood as in the anhydrous state.

	Degrees.
Total hardness	37
Permanent hardness	20
Temporary hardness	17

The total and the permanent hardness were determined by the use of a standardized soap solution. The temporary hardness is found by subtracting the permanent from the total.

The U. S. gallon of 231 cubic inches is the basis of these results, not the imperial gallon, as formerly customary.

This analysis shows that the water is of good quality for domestic use and for irrigation. For table use, like the water of all streams in this vicinity, it would be improved by boiling and settling. This process removes a considerable part of the mineral matter and destroys infusoria and other living organisms. For use in steam boilers it would be advisable to submit this water to a softening treatment before taking it into the boilers.

DISCUSSION OF ANALYSES.

Up to January 28, 1903, this season was not productive of floods, the precipitation having been largely in the form of snow in the higher mountains, and the high water occurring later in the spring. For this reason all of the samples except Nos. 6, 7, and 12 were taken when the stream was at low stage. The water that runs off the surface of the ground in floods will not contain as much mineral matter as that which seeps through the soil into the stream during its low stage. Samples Nos. 12 and 13 show this to be true. It is probable that over 80 per cent of the total annual discharge of the Mono will be in freshets. This being the case, we may expect the water that is stored in reservoirs to be more nearly like the flood-water than the low-water samples analyzed. If the low-water flow tends to deteriorate the whole impounded in the reservoir, it may be carried around the reservoir in a conduit.

The first flood that is flushed over the surface of a drainage basin after a drought will absorb more mineral matter than later floods will find. Thus sample No. 12 shows better water than No. 7. Sample No. 12, from the second flood water of the Mono, shows a water practically the same as that now being used by the city of Santa Barbara from Mission Creek and the city tunnel. The low-water samples contain a high per cent of mineral, but even they are pronounced harmless by Mr. Dodge. The water of the Santa Ynez above the Mono is better than the Mono water. The water stored at the Gibraltar site would be a blended water, grading between the two; and in view of the fact that this is the only source of supply open to the city for an adequate amount of water, it is believed that it should be accepted.

Prof. James A. Dodge, a chemist of marked and recognized ability, residing at Santa Barbara, who made a number of the foregoing analyses, gives the following statement about the quality of this supply:

> On the supposition that the proposed reservoir on Mono Creek will be filled with the flood water of the creek, but that the water running in the creek during its low stages will also pass into the reservoir, the water as supplied to this city from that source will in its composition come between the samples analyzed by me and reported on the 16th and 21st of February [No. 12] and the 4th of March [No. 14], and might under certain conditions approximate to the first of these samples.
>
> Considering, therefore, this low-water sample, I call attention to the fact that the principal mineral ingredients—that is, those present in greatest quantity—are the familiar calcium and magnesium salts of our hard waters. A person drinking a quart of this water would take into his stomach from 12 to 13 grains of these salts. He would at the same time take about 5 grains of sodium salts, equally common in our natural waters as used for domestic purposes, together with a very small amount of other harmless mineral substances.
>
> In my opinion, these quantities of all these substances, taken in water, would not be sufficient to produce any deleterious or unpleasant effects upon a person in good health, properly supplied with food. Nor would the habitual use of the water bring about any bad consequences. In the case of some persons in delicate health, or of persons fasting, the same substances in the same quantity contained in the water would probably have the medicinal action of an aperient. This opinion is based on actual experience in the use of such water by myself and by others in the same company.

I will add that this water by being boiled would be caused to deposit a part of the calcium and magnesium salts, in the form of carbonates, and would thereby be improved. Furthermore, aside from the removal of a part of the mineral matter, all water taken from streams and lakes, in view of the possibility of its contamination by disease germs, needs boiling to make it perfectly safe for domestic use. After being boiled and decanted from the precipitated substances, the water, if placed in a suitable receptacle, will keep as long as may be desired and will be quite potable from first to last.

As regards the use of the Mono Creek water for cooking purposes, in my opinion the quantity of mineral substances introduced into the articles cooked with it would not be sufficient to produce any noticeable effects.

For washing this is a hard water. It would, with ordinary soaps, be somewhat more troublesome than the waters now supplied to the people of this city.

In the irrigation of trees, shrubs, and other plants, this water would not produce any injurious effects, unless applied in extraordinary quantity or on soil with little or no drainage.

It must be admitted that these waters are not of high grade for domestic use because of the large quantities of mineral matter in solution, but it is not believed that they will be injurious to health, nor will they be harmful to vegetation. The sulphate of sodium is not harmful, and the sulphate of lime tends to neutralize the carbonates. All stream waters contain more or less mineral matter. Chemically pure water is neither pleasant to drink nor healthful. The question of soils becoming alkaline from irrigation with salty water is largely dependent upon the slope and drainage that the soil itself has. In a hill country water containing unusual quantities of alkali may be used with impunity, while in a flat country a water of much better grade could not be applied in irrigation without producing bad effects. No organic impurities, which are most to be feared, will be found in these waters in dangerous quantities.

It should be stated that the samples Nos. 4 to 11, given Professor Stabler, were not large enough in volume to permit of complete analysis.

Mr. Thomas H. Means,[a] of the Bureau of Soils of the Department of Agriculture, makes the following comment upon the quality of the water as indicated by the foregoing analyses:

I have examined the analyses given in your report to the city water commissioners of Santa Barbara, Cal., with a view to determining whether these waters would be considered favorable for city use or not. I have considered the sources as free from contamination through animals and consequently have confined my attention to the mineral ingredients which the water carries.

As I understand the situation, the water which you propose to carry through the mountains by a tunnel is to be stored in a reservoir on Santa Ynez River and comes in something like equal parts from Santa Ynez River and Mono Creek. The analyses in your report are from samples taken from both streams. The following table is a recapitulation of the analyses, showing only the total solids in 100,000 parts of water:

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[a] Mr. Means has since been appointed engineer of soils of the Reclamation Service.

Comparison of analyses of Santa Ynez and Mono water.

Date.	Stage of Santa Ynez River.	Parts per 100,000.	Date.	Stage of Mono Creek.	Parts per 100,000.
1903.			1903.		
Jan. 4	Low stage before floods.	73.60	Jan. 4	Low stage before floods.	140.00
Nov.[a] —	First flood	116.00	Nov.[a] —	First flood	98.00
Jan. 29	Low stage	60.00	Jan. 29	Low stage	97.20
30	.....do	69.20	30	.....do.?	112.00
			28	Flood	48.30
			26	Low water	110.69
			26	.....do	129.00

[a] 1902.

All of these samples, with one exception, are collected at low stage of the stream, when the amount of soluble matter is usually highest, or at first flood after the dry season, when the accumulations of saline matter from the surface of the soil are swept into the stream. So these analyses probably represent the worst condition of the water. The only flood sample is that from the Mono Creek collected January 28, 1903, and its analysis shows considerably less than half the soluble matter found in the low-stage flow of the stream. I presume if flood samples were collected from the Santa Ynez a similar falling off in amount of soluble matter would be noted. The importance between this difference in low-water and flood stages is very great, especially where the floods can be stored and where it may be possible to divert the low-water flow and carry it around the reservoir.

The waters of Mono Creek seem to carry much more soluble matter than do those of the Santa Ynez. The average of the analyses given under the first four dates in the table shows Mono Creek to carry nearly 49 per cent more soluble matter than does Santa Ynez River. If the same ratio holds during the flood season the mixture of waters in the two streams should carry less than 40 parts per 100,000 parts of water, or a water, as will be shown later, which, according to the most rigid standards in eastern cities and in Europe, would be classed as "good" for domestic use. On the other hand, if the low-water discharge alone is considered the average of a mixture of the two waters would be about 114 parts per 100,000. Later I will show that according to accepted standards this amount of soluble matter is well within the limit of western American sanitary engineers.

The standard most generally accepted in eastern United States and Europe allows 50 parts per 100,000 parts of water. More than that quantity serves to condemn a water or class it as a water only "fair" for domestic use, while waters carrying less than 50 parts are classed generally as good. E. W. Hilgard, of the University of California, places the limit for domestic use at 40 grains per gallon (68.6 parts per 100,000). J. K. Haywood, chief of the water laboratory of the Bureau of Chemistry in the United States Department of Agriculture, in an article on Analysis of Waters and Interpretation of Results, published in the Department of Agriculture Yearbook for 1902, makes the following statement: "Some water analyzers would cast aside all doubt by declaring that waters containing above 686 parts per million (68.6 parts per 100,000) are to be condemned, but such is not the case, as there are many instances, especially in the West, of water containing 1,200 parts per million (120 parts per 100,000) and over being used without apparent evil results."

As a matter of precedent, I might say that there are a number of small western towns using water carrying more than 100 parts soluble matter per 100,000 parts of water, and that the city of Phoenix, Ariz., supplies about 15,000 people with water carrying from 102 to 136 parts, without apparent inconvenience or harmful effect. Numerous domestic supplies for families have been observed by myself carrying from 400 to 500 parts per 100,000, all without evil effect and with no inconvenience except that the waters were unpalatable at first. The inhabitants of some parts of the Southwest have become so used to the saline waters that I have seen pure water salted at table to bring back the familiar taste

I find it very difficult to draw any definite conclusions from the character of the salts in the water, for I am not familiar with the methods employed by the chemists in calculating these analyses. However, it seems that the most important constituents are salts of lime. These serve to make the water hard, will cause considerable losses in soap used, and will give trouble in boiler use by forming scale. I can not say how much of this hardness is "temporary" and how much "permanent." The two analyses, Nos. 13 and 14, are evidently made from duplicate samples by two chemists working independently. One of them, No. 13, would be classed as a hard water with nearly all the hardness permanent, or, in other words, it could not be removed by boiling. On the other hand, when we consider analysis No. 14, nearly one-half of the hardness is temporary, or could be removed by simply boiling and allowing the sediment to settle. If a new set of analyses were made I would suggest they be made by some accepted standard of water analyses and both "temporary" and "permanent" hardness be determined.

Of the other salts present only the sodium sulphate and magnesium sulphate are present in sufficient quantity to warrant consideration. Both these salts are laxative, but only the most delicate constitutions would be affected by the small amounts taken in this water. Newcomers to the locality might notice the effect of the water for a few days, but I am sure no evil effects can possibly come from the constant use of such water.

The small amounts of sodium carbonate would either neutralize the effects of part of the calcium sulphate or would react with some of the magnesium salts to lower the amount of "permanent" hardness. The amount of sodium chloride is so small as to be negligible in considering the value of the water.

In summing up the matter I will say that I think the flood flow of the united Santa Ynez and Mono will prove to be well within the limits set down by the most rigid eastern standards, and that from the available analyses even the low-stage flow will be found to be well within the limits allowable for western cities and much lower in salt contents than many waters which have been in use for a long time without deleterious effects.

If further analyses are made I would suggest that both "temporary" and "permanent" hardness be determined and that some attempt be made to collect flood samples as well as the normal and low stage from both streams.

In respect to the amount of solid matter in the stream, it will be seen that there was less silt in the first flood water from the Mono than from the Santa Ynez; the reverse may be expected under ordinary conditions. Both of these analyses show the percentage of wet silt by volume at the expiration of a short period of settlement. This determination of solid matter by volume gives an exaggerated idea of the way in which the silt might be expected to destroy the storage capacity of the reservoir, for it will compact as it settles in the reservoir and as other silt is deposited upon it. In this manner it will solidify into soil occupying from one-half to one-quarter of the space indicated by its volumetric determination. Later floods have shown less than one-tenth of 1 per cent of silt.

The way to meet the silt problem in the future will be by building the dams higher when their storage capacity is impaired. The elevation of the bed of the creek at the Mono reservoir site is 1,440 feet; the capacity to the 1,530-foot elevation is 6,509 acre-feet. If the water level is raised 10 feet, or to the 1,540-foot elevation, the capacity will be increased 2,254 acre-feet, or 34.6 per cent. If we consider that the reservoir will lose as much as 2 per cent of its capacity annually by silting, or 34 per cent in seventeen years, the original capacity could be restored by raising this dam 10 feet in height at the end of that period of time. In a similar manner the capacity of the Gibraltar reservoir may be increased about 30 per cent by raising the crest 10 feet above the 155-foot elevation.

FOREST COVER.

The true and permanent solution of this silting problem lies in the protection and development of the forest and brush cover of this reserve. A valuable brush cover is shown in Pl. III, *B*. Under existing conditions the Los Prietos Y Najalayegua grant is wedged in between the Pine Mountain and Zaca Lake Forest Reserve and the Santa Ynez Forest Reserve, along the canyon of Santa Ynez River. This private grant is not only pastured to sheep and goats, but is also subject to attacks from fires originating thereon which can not be properly restrained. Sheep have been described as the hoofed locusts of the mountains. Their small feet cut up and pulverize the soil, destroying the plants and roots that might otherwise escape them. They are a menace almost equal to that of fire to every drainage basin in southern California which they enter. Arrangements, if possible, should be made looking toward the condemnation of this property in some way and its addition to the forest reserves above referred to. The board of water commissioners of Santa Barbara very wisely and properly have urged this matter with the Departments at Washington, and the forestry experts who have examined the region have favorably reported upon the action suggested.[a]

With a natural increase of vegetation and protection from the fires which have raged through this district for years past it is believed that the silt danger would be largely mitigated. This is a subject which should be followed up as one of vital importance, and but one solution should be permitted, to wit, the expulsion of the sheep from the drainage basin of the Santa Ynez and the protection of the forest and brush cover from fire. Otherwise the drainage basin is satisfactory. There are practically no human habitations within its borders above the proposed reservoir sites, and probably will be none in the near future, as the country is too mountainous and too inhospitable to admit of agricultural pursuits. The greater portion of the basin is now included in forest reserves.

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[a] In December, 1903, after the above had been written, an Executive order included this grant in the forest reserve, an exchange of holdings having been arranged with the owner, and now the entire reservation, including the whole basin of the upper Santa Ynez, is known as the Santa Barbara Forest Reserve.

RESERVOIR SITES.

JUNCAL SITE.

Mr. George Wright made surveys of the Juncal reservoir site and determined the following capacities:

TABLE 14.—*Capacities of the Juncal reservoir site for various heights of dam.*

Height of dam in feet.	Million gallons.	Acre-feet.
50	350	1,074
75	705	2,164
100	1,050	3,222
125	1,437	4,410
150	1,877	5,760
175	2,352	7,218
200	4,000	12,276

It will be noted that with a dam 100 feet high the capacity of the Juncal reservoir is 3,222 acre-feet; with a 100-foot dam on the Mono reservoir site the capacity is 8,763 acre-feet. The Mono site, therefore, has 2.72 times the capacity of the Juncal, with the same height of dam. The Gibraltar dam, 100 feet high above stream bed, will hold 6,480 acre-feet. It is believed that the Juncal reservoir site alone will not furnish an adequate water supply to the city, but when used in connection with other reservoir sites having greater drainage areas above them it may be of value. The drainage area above the Juncal is but 13.4 square miles, not 23½ square miles as reported upon previously by other engineers. The length of a dam 200 feet high at the Juncal would be 550 feet on top, and a 100-foot dam would be 272 feet.

Mr. Purslow estimated that the cost of building a 100-foot dam and a riveted-steel pipe line (which latter must be considered as temporary construction) to Santa Barbara would be $282,450. He also states that the run-off from the drainage basin of the Juncal was measured in the winter of 1895–96 and that it amounted to 2,455 acre-feet. On the other hand, it is estimated in this report (see p. 53) that the run-off of the Juncal in 1895–96 was only 520 acre-feet from 13 square miles—a figure, therefore, apparently overconservative. However, there probably was a flood in January, 1896, as the rainfall for that month was 6.84 inches at Santa Barbara and probably 9 inches in the drainage basin of the Juncal. This may have produced a rather abnormal flood condition. As Mr. Purslow gives no details of his work, not even the length of time of his observations, his results can not be accepted as conclusive.

Mr. Wright states that the rock at this dam site, which is quite similar to the formation prevailing throughout this region, weighs 149 pounds per cubic foot. In this estimate this rock has been considered as weighing 150 pounds per cubic foot, as determined at various points along the Coast Range by geologists. Masonry work made therefrom is taken to weigh 143 pounds per cubic foot.

MAIN RIVER SITE.

The Main River reservoir site was investigated by Mr. Purslow. This also was surveyed by W. B. Clapp for the Geological Survey. We find that a dam 65 feet in height would have a storage capacity of 1,311,000 gallons, or 4,023 acre-feet, to the 65-foot flow line. Figs. 2 and 3 show the reservoir and dam sites. The Mono reservoir site with water held to the 75-foot level would have a capacity of 3,968 acre-feet. The Main River dam, however, would contain very much more masonry and be more expensive than the Gibraltar or the Mono dam. A dam 75 feet high at the Main River site would be 592 feet long on top and 427 feet long on the base. At the Mono dam site a dam 75 feet high would be 277.5 feet long on top and 150 feet long at the bottom. The Gibraltar is still more favorable. With an 85-foot rock-fill dam at the Mono the cost per acre-foot of capacity is $36, while at the Main River site with a 65-foot concrete dam the cost is about $154 per acre-foot of capacity, depending on depth of bed rock.

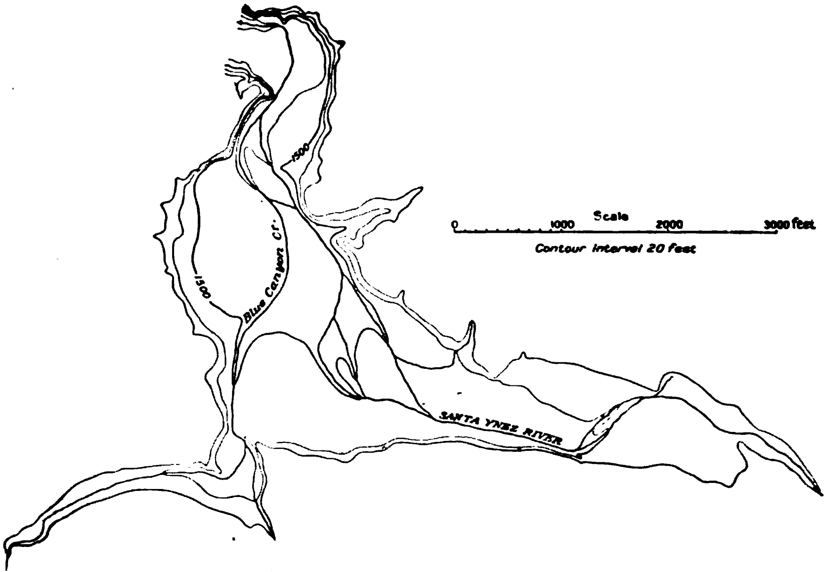

FIG. 2.—Main River reservoir site.

Mr. Purslow states that it would require a tunnel 15,500 feet long to pass through the Santa Ynez Range to the coast side and that the estimated cost of developing this work would be $557,000. It is believed that a shorter location can be found. The width of canyon covered by débris at the Main River dam site is so great and the depth to bed rock so uncertain that it is impossible to give even an approximate estimate of the cost of this dam. It must be of masonry, as it will have to be an overflow weir. If bed rock is taken as 25 feet below the bed of the creek, it may cost $620,000 for the dam alone.

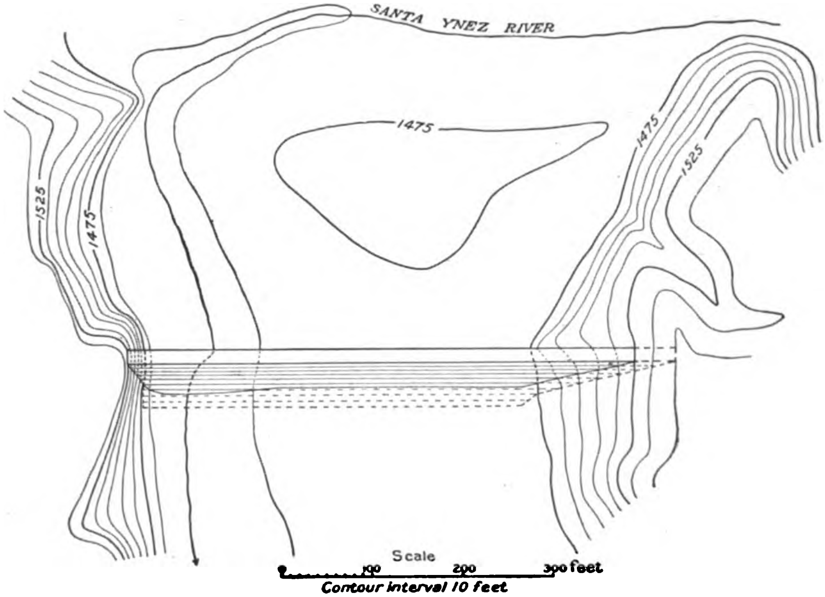

FIG. 3.—Main River dam site.

The effort has not been made in this report to go into the details of these estimates of cost for the Main River and Juncal reservoir sites. The reservoir sites are owned by the Santa Barbara City Water Company. It is believed, however, that if the city of Santa Barbara constructs a tunnel through the Coast Range, in order to lead the water from the lower reservoir sites to the city, the construction by some one of the Juncal or Main River reservoir sites may ultimately follow. This tunnel is a very large element in the cost of the work, and will require by far the greater length of time to construct. It must be so located as to permit the water from all the sites to be led through it by gravity to the coast, and its capacity must be sufficient to accommodate all of the water.

TABLE 15.—*Area and contents of Main River reservoir.*

[Survey by W. B. Clapp.]

Contour.	Acres.	Acre-feet between contours.	Total acre-feet to contour.	Capacity in millions of gallons.
1,460	0.33			
1,470	2.68	15.05	15.05	5
1,480	14.38	85.30	100.35	33
1,490	30.45	224.15	324.50	106
1,500	71.59	510.20	834.70	272
1,510	120.19	958.90	1,793.60	581
1,520	154.69	1,374.40	3,168.00	1,032
1,530	187.66	1,711.75	4,879.75	1,590
1,540	222.06	2,048.60	6,928.35	2,357
		6,928.35		

75-foot flow-line capacity=5,904.05 acre-feet.
Depth of bed rock unknown.

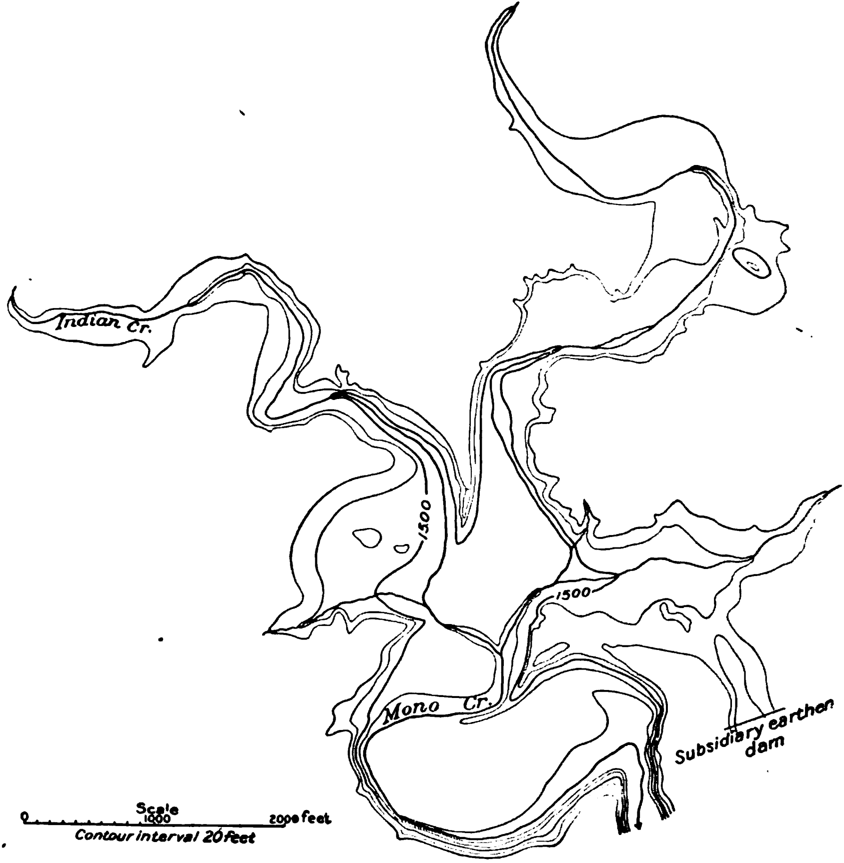

FIG. 4.—Mono reservoir site.

BLUE CANYON SITE.

The Blue Canyon reservoir site is situated in what is known as Blue Canyon, which discharges into the Santa Ynez a short distance above the Main River reservoir site. It is a good reservoir site, but as the drainage basin is only 8 square miles it is not considered feasible to fill it from its tributary natural-water supply. The Blue Canyon reservoir site is between Santa Ynez River and the crest of Santa Ynez Mountains. The length of tunnel from this reservoir site to the coast side would be 10,500 feet. To fill it from Santa Ynez River, in addition to building this long tunnel, would be too expensive a proposition to justify the construction.

MONO SITE.

A detailed and careful survey was made of the Mono reservoir and dam site by Mr. W. B. Clapp, of the hydrographic branch of the Geological Survey. Fig. 4 shows the results of these surveys, and Pl. IV, *B*, is a view of the site. The following table gives the capacity:

TABLE 16.—*Area and contents of the Mono reservoir site.*

[Survey by W. B. Clapp.]

Contour.	Area in acres.	Capacity in acre-feet between contours.	Total capacity in acre-feet.	Capacity in millions of gallons.
1,440.0	0	....	....	....
1,450.0	1.2			
1,460.0	10.6	....	[a] 94.0	....
		59.0	....	....
1,461.2	....	209.0	00.0	....
1,470.0	31.2	....	174.0	57
1,480.0	49.9	406.0	580.0	189
1,490.0	71.3	606.0	1,186.0	386
1,500.0	98.1	847.0	2,033.0	662
1,510.0	125.4	1,117.5	3,150.5	1,026
1,520.0	164.0	1,447.0	4,597.5	1,498
1,530.0	199.5	1,817.5	6,415.0	2,090
1,540.0	251.4	2,254.5	8,669.5	2,825

[a] Below outlet.

Total capacity in acre-feet	8,763.5
Capacity below outlet	94.0
Capacity, above outlet	8,669.5
Elevation of creek bed	1,440.0
Elevation of outlet	1,461.2

Depth of bed rock unknown.

This reservoir site has tributary to it a drainage area of 119 square miles. The creek passes first through a large flat and then through a narrow gorge. It is an unusually good reservoir site for southern California, but the dam site is poor. If the tunnel which the city is now running is continued at a grade of one-tenth of a foot rise to 100 feet horizontal, the elevation of the north portal of the tunnel on the datum plane that has been used will be 1,457.2 feet.[a] We may assume that a conduit leading from the reservoir site to the portal of the tunnel would descend approximately 4 feet in grade, giving an approximate elevation of the outlet from the reservoir as 1,461.2 feet, or 21.2 above the bed of the stream at the reservoir site. This is not of material consequence, as it is usually the case with reservoir sites that the first 20 or 30 feet above the bed of the stream at the dam site has very limited storage capacity. Thus the total storage capacity to the 100-foot flow line at the Mono reservoir site is 8,763.5 acre-feet and the capacity below the outlet is but 94 acre-feet, so that the net capacity above this outlet with a 100-foot dam would be 8,669.5 acre-feet, or 99 per cent of the total.

DISCHARGE.

Measurements of the flow of the Mono during the winter of 1902–3 were made daily, and the discharge for the season was found to be as follows:

TABLE 17.—*Estimated monthly discharge of Mono Creek at the dam site for season of 1902–3.*

[From daily measurements.]

1902.	Acre-feet.	1903.	Acre-feet.
July	0	January	676
August	0	February	389
September	0	March	1,845
October	0	April	4,820
November	173	May	799
December	12	June	220
		Season	8,934

The mean rainfall at Santa Barbara is 16.78 inches; for the last season it was 20.45 inches. Although the precipitation was in excess of the mean, the rainfall was not delivered in such manner as to produce large stream discharge and in the opinion of local residents the streams were below normal. The five preceding years were all below the mean in precipitation, so that a larger portion of the water than usual was absorbed by the ground. These measurements of the streams should be continued so that the height of dam may be intelligently proportioned to the probable water supply. (See table 12, p. 53, showing estimated volumes of flow annually.)

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[a] For more detailed statement, see p. 40.

CONTENTS AND COST OF DAMS.

Two types of dam for the Mono site have been considered. The rock on the sides of the canyon at this dam site is sandstone and shale, the stratification being practically vertical and the strike at right angles to the direction of the stream flow. Pl. IV, *A*, shows the character of this rock at the left abutment, which is the best. It weighs approximately 150 pounds to the cubic foot, and could be quarried in sizes and forms suitable for the work on the dam. The abutments are much better at the Mono dam site than at the Main River dam site, but not so good as at the Gibraltar. Spillway opportunities occur at the right abutment for the accommodation of flood discharges when the reservoir may happen to be full. The dam is considered in each instance to be 10 feet above the elevation of its spillway, so as to prevent the water overtopping the structure. The depth to bed rock is not known. The most serious item in connection with the construction of the dam is probably the transportation of supplies and materials to the site. In case the dam should be a cement, masonry, or concrete structure there would be a large amount of cement, which is a heavy material, to be hauled to the reservoir site. The masonry dam is believed to be the better form of construction, but because of considerations of economy the cost of the rock-fill type of dam has been computed.

These supplies for a rock-fill dam would probably be hauled by teams up Santa Ynez River from the end of the railroad at Ballard, a distance of 40 miles, or possibly through the tunnel when it is completed. The wagon road would be poor for the last 10 miles, but the grades easy. In the original estimate for this dam made for the city of Santa Barbara all material was considered as hauled by wagon to the dam site for both forms of structure. Since then (January 1, 1903) the manufacture of native cements has reduced the price of this constituent materially.

The rock-fill may be the better type for this point because of its greater economy. As the volume of material that would have to be brought in for construction purposes would be relatively small as compared with a masonry dam, it probably would not be advisable to provide for transportation through the tunnel for it, as would be necessary if a masonry dam were built. The estimates are therefore made upon this assumption. Fig. 5 shows a plan for a 110-foot rock-fill dam and fig. 6 a plan for a subsidiary earthen dam.

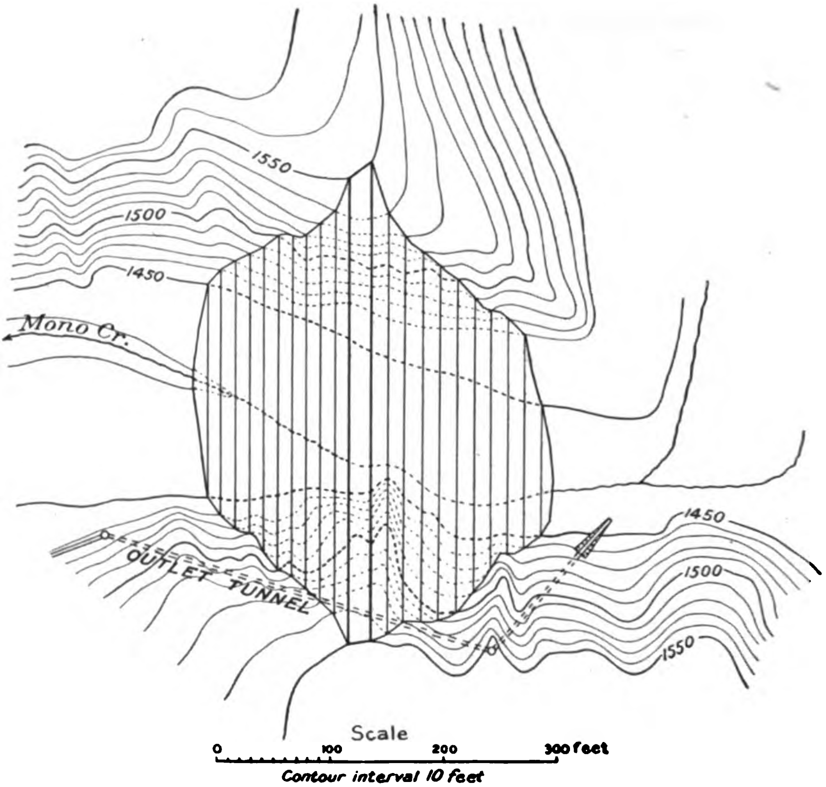


FIG. 5.—Mono dam site, showing 110-foot loose-rock dam.

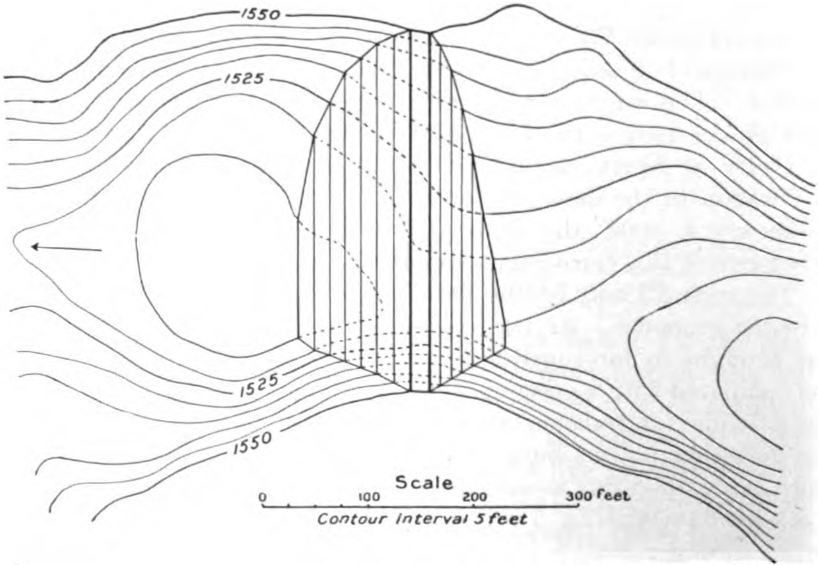


FIG. 6.—Mono dam site, showing plan of subsidiary earth dam for 110-foot loose-rock-fill dam.

All engineers connected with these investigations have declared that it is quite necessary, before preparing an accurate report and estimate on the reservoir sites, to know the position of bed rock at the place where the structure is to rest, and have recommended that these explorations should be carried out in connection with this present investigation. It has been found impossible, however, at this writing, to supply the funds to make this examination, and consequently the estimate must be taken with latitude in this regard.

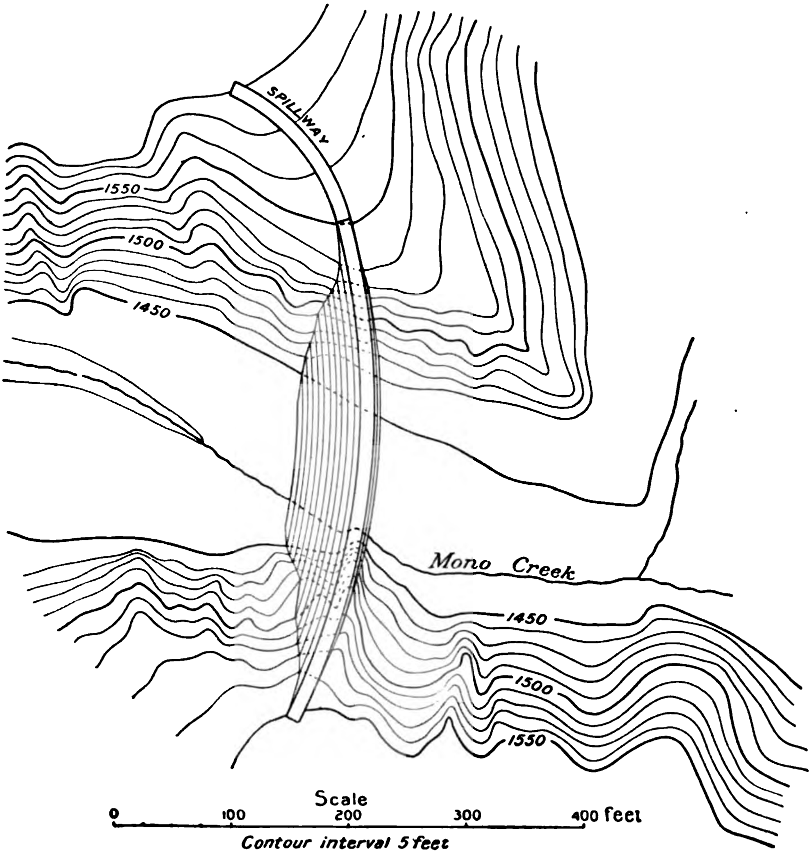


FIG. 7.—Mono dam site, showing plan for 110-foot concrete dam.

In the case of the rock-fill dam, it could rest properly and safely upon the present bowlder-covered bed of the canyon, but it would be necessary to carry down to bed rock on the upper slope an apron wall to cut off the underflow beneath the dam. This wall would be connected with a portion of the apron of the dam above ground in order to make it completely tight. It should be 8 feet thick at its base and 4 feet thick on top at the ground surface, so that for a loose-rock dam there would not be a great quantity of material to be removed from the bed rock, and the amount of cement used would be small

In the case of a concrete or masonry dam, however, the whole structure would have to go down to the bed-rock foundation, which would have to be exposed and thoroughly cleaned. In estimating on the concrete dam it has been assumed that bed rock for the entire width of the canyon is 20 feet beneath the surface of the ground. At a point some 200 or 300 feet below the dam site a ledge of material projecting well out into the canyon, over which the stream flows, has the appearance of being bed rock or ledge matter in place. It is not known, however, whether it extends completely across the stream.

An 85-foot rock-fill dam at the Mono reservoir site would contain 75,480 cubic yards of loose rock, which, it is considered, could be quarried from cliffs that are favorably situated for $1 per cubic yard. Each yard, so thrown into the fill, would make 1¾ yards of fill; consequently a figure of 60 cents per cubic yard has been accepted. A dry-laid wall 2 feet in thickness on the upper face of the dam is provided for, upon which the asphalt-concrete apron will be laid. The upper toe wall is carried down to bed rock in the bed of the stream, 4 feet thick on top, 8 feet at base, and 20 feet high. On the sides of the dam this wall is also estimated upon to seal the asphalt-concrete to the abutments. The asphalted concrete will be put on 1½ feet thick, of broken stone, gravel, sand, and asphalt, the latter being brought from quarries on the lower Santa Ynez. The section of this dam will be 20 feet wide on top, with a very flat slope of 1½ feet horizontal to 1 foot vertical on the upper face and 1¼ feet to 1 foot on the lower face. This flat slope is given to the upper face so that there will be no movement in the asphalt apron. The asphalt also would be rammed into the crevices of the dry-laid wall on which it rests.

The spillway provisions are of vital importance in a rock-fill dam. The maximum flood that was ever measured on Sweetwater River since the dam was constructed there, some fifteen years ago, was 98 cubic feet per second for each square mile of the drainage basin. A flood discharge of Piru Creek was measured at Henderson's ranch on December 18, 1894, of 43 cubic feet per second per square mile of drainage area. On Arroyo Seco, a tributary of the Salinas in Monterey County, on November 21, 1900, a flood of 140 second-feet per square mile was observed. The rainfall, however, in the drainage basin of Arroyo Seco is exceedingly heavy. For the purposes of this report we have assumed a flood of 130 second-feet per square mile of drainage area, or a total flood discharge of 15,470 second-feet, filling the spillway to within 3 feet of the top of the dam. Before the spillway would be filled to the top of the dam the flood would have reached

26,420 cubic feet per second, or 222 second-feet per square mile of drainage basin. The spillway would be 251 feet long and the bottom of it would be 10 feet below the crest of the dam. It would be excavated from the rock at the right abutment of the dam.

A 20-inch pipe has been estimated upon, leading from the Mono reservoir site to the intake of the long tunnel through Santa Ynez Range of mountains. The aggregate cost of reservoir and pipe line to long tunnel is $140,700, or $36 per acre-foot of capacity.

In estimating upon the length of tunnel line through the Coast Range to this reservoir site we have accepted the present tunnel site and assumed that the tunnel is to be completed on an angle line, or in such manner as to avoid the property of all owners other than the city of Santa Barbara. On this basis there would still be 15,006 linear feet of tunnel to run, at an estimated cost of $12 per linear foot.

Estimate for 85-foot rock-fill dam at Mono reservoir site.

[Capacity 3,880 acre-feet.]

DAM.

75,480 cubic yards of loose rock, at 60 cents per yard	$45,288	
2,500 cubic yards of dry-laid wall (upper face), at $1 (extra)	2,500	
Upper toe and side wall to bed rock	16,500	
Asphalt-concrete face 1½ feet thick, 1,861.2 cubic yards, at $8	14,890	
Outlet tunnel, gates, and tower	10,000	
Spillway	20,000	
Clearing reservoir	2,460	
20-inch pipe line to long tunnel 7,000 feet from reservoir, capacity 189 inches	10,710	
Engineering, 5 per cent	6,117	
Contingencies, 10 per cent	12,235	
Total ($36 per acre-foot)		$140,700

TUNNEL.

15,006 linear feet of tunnel through Santa Ynez Range, via angle line, at $12 per foot	$180,072	
Road up Santa Ynez River	5,000	
Engineering, 5 per cent	9,254	
Contingencies, 10 per cent	18,507	
Total		212,833
Grand total		353,533

An estimate is also presented of the cost of building a rock-fill dam at the Mono to an elevation of 110 feet above the bed of the stream, impounding the water to the 100-foot flow line. The conditions would be the same for the construction of this dam as in the case of the 85-foot dam, except that a second small earthen dam would have to be built to close another opening; this is referred to as the subsidiary dam. With the rock-fill type of dam it would be quite feasible to increase the height, raising the dam to such new elevation as might be desired.

Estimate for a 110-foot rock-fill dam at Mono reservoir site.

[Capacity 8,670 acre-feet, 290 miner's inches constant flow.]

142,535 cubic yards of loose rock, at 60 cents per yard	$85,521	
3,733 cubic yards of dry-laid wall, at $1 (extra)	3,733	
Upper toe and side walls	18,099	
Asphalt-concrete face 1½ feet thick, 2,772 cubic yards, at $8	22,176	
Outlet tunnel, gates, and tower	10,000	
Spillway	20,000	
Clearing reservoir, 257 acres, at $15	3,855	
Pipe line to long tunnel, 7,000 linear feet, capacity 366 inches	12,880	
25,745 cubic yards earth in subsidiary dam	7,724	
Engineering, 5 per cent	9,199	
Contingencies, 10 per cent	18,399	
Total ($24.40 per acre-foot)		$211,586
Tunnel through Santa Ynez Mountains, as above		212,833
Grand total		424,419

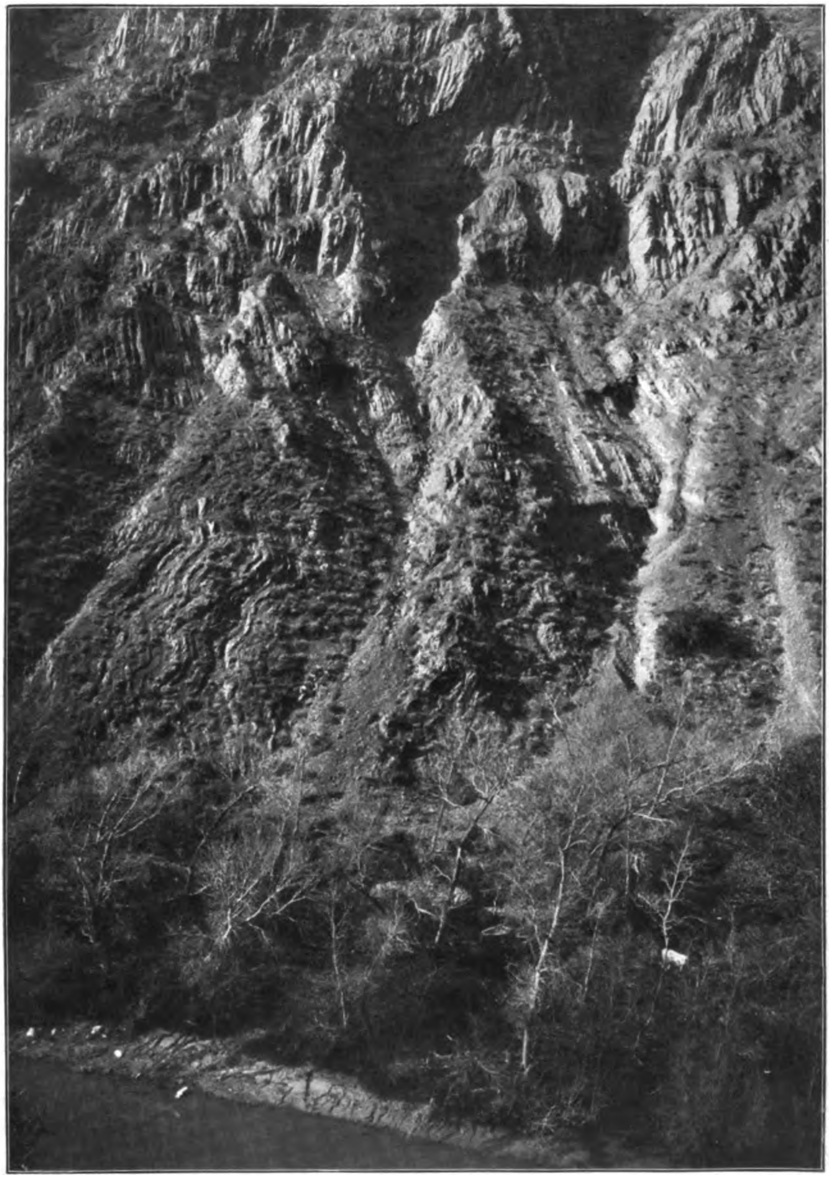
An estimate is also given for a masonry dam 85 feet high at the Mono reservoir site. This dam would be 12 feet wide on top, with a slope of 2 to 1 on the lower side and 20 to 1 on the upper side. The masonry would be made of hydraulic cement, which would be hauled through the finished tunnel. The outlet, tower, spillway provisions, and clearing reservoir would be the same as in the case of the rock-fill dam. The total cost of a dam of this class, including the 20-inch pipe line to the long tunnel, would be $361,690, or $93 per acre-foot of storage capacity. It thus will be seen that the masonry dam 85 feet high would cost 2.6 times what the loose-rock dam would cost. This is because the latter would be built of material at hand.

Estimate for 85-foot masonry dam at the Mono reservoir site.

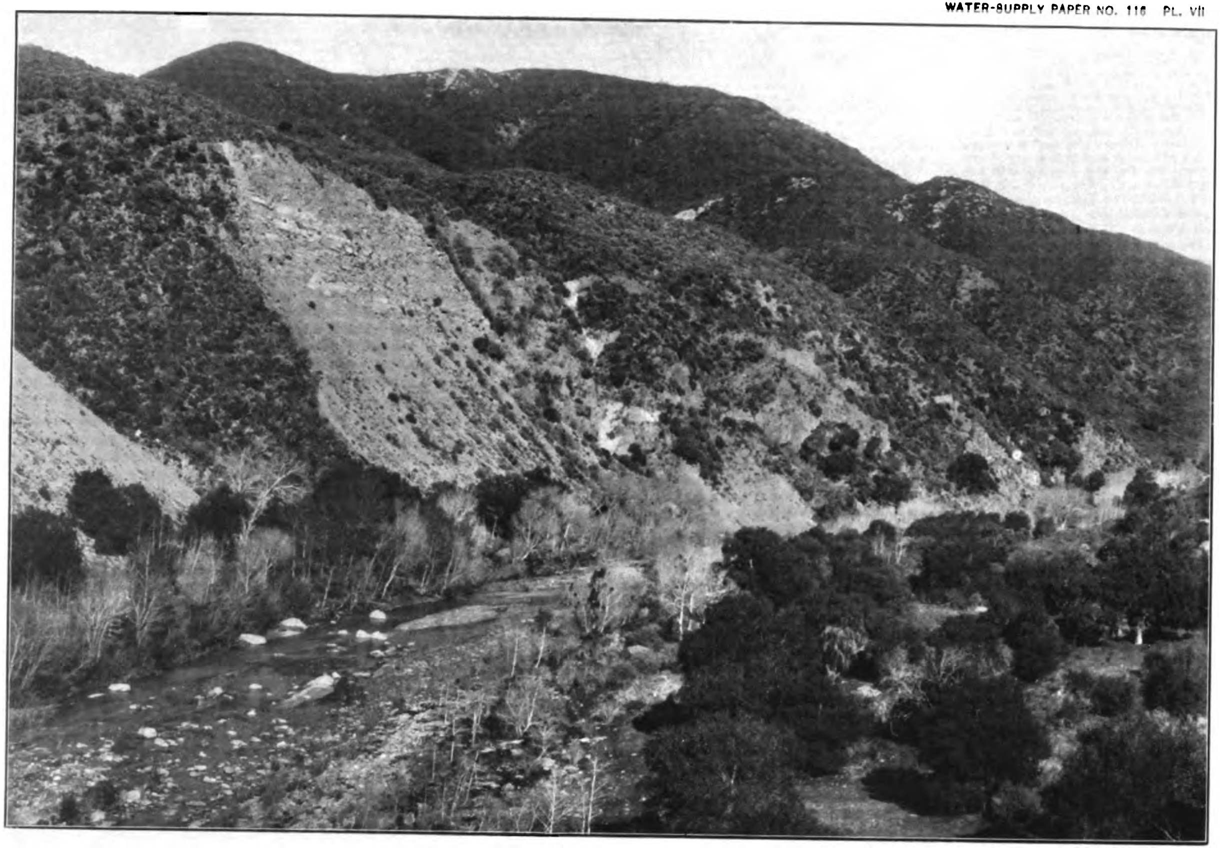
[Capacity, 3,880 acre-feet.]

6,612 cubic yards masonry below surface of ground, at $15 (includes excavation)	$99,180	
22,955 cubic yards masonry above ground	172,163	
Total for dam proper		$271,343
Outlet tunnel, gates, and tower		10,000
Spillway		20,000
Clearing reservoir		2,460
7,000 feet of 20-inch conduit, capacity 189 inches		10,710
Engineering, 5 per cent		15,726
Contingencies, 10 per cent		31,451
Total		361,690

Cost per acre-foot of capacity, $93.



QUICKSILVER MINE DAM SITE, RIGHT ABUTMENT.



QUICKSILVER MINE RESERVOIR SITE.

View upstream from dam site.

QUICKSILVER MINE SITE.

A site called the Quicksilver mine reservoir site was discovered about 4 miles below the mouth of the Mono. At this point the river passes through a rather narrow canyon of shale rock, shown in Pl. VI. The site itself is shown in Pl. VII. The capacity of this reservoir is large, but the dam site is not satisfactory because of the absence of suitable building material, and also on account of the character of the abutments. Figs. 8 and 9 show the reservoir and dam sites.

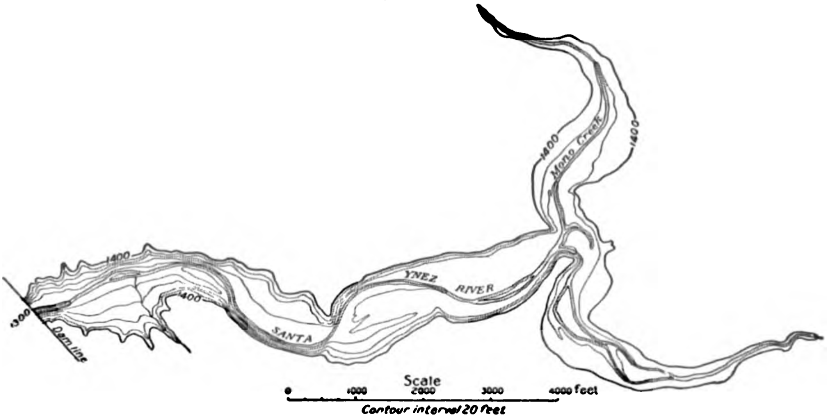


FIG. 8.—Quicksilver mine reservoir site.

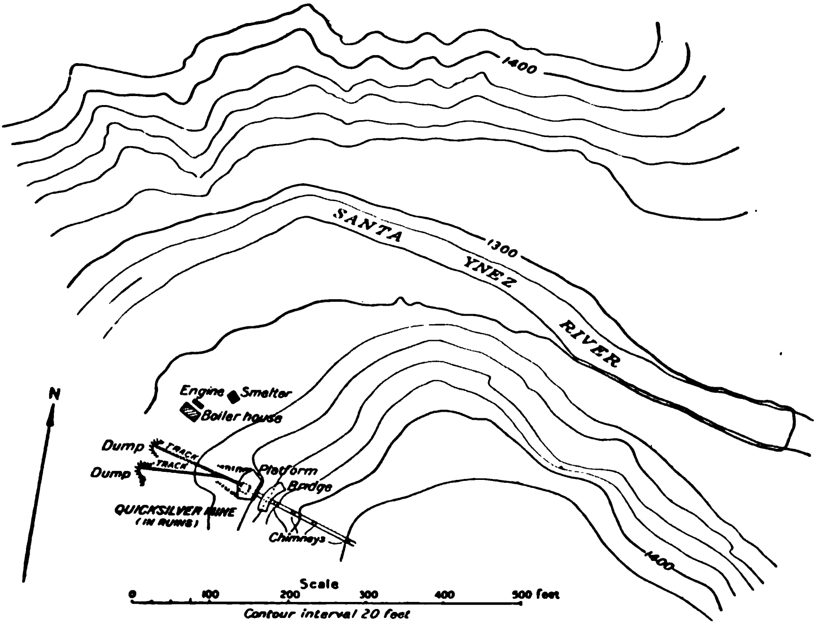


FIG. 9.—Quicksilver mine dam site.

Water impounded to a depth of 100 feet in this reservoir would be flooded back a short distance into the Mono and up the Santa Ynez above the mouth of the Mono. The following is a table of the capacity of this reservoir.

TABLE 18.—*Capacity of Quicksilver mine reservoir site.*

Contour.	Area in acres.	Average area in acres.	Capacity in acre-feet.	
			Between contours.	Total to contours.
1,300	0.57	3.70	37.0	37.0
1,310	6.83	12.05	120.5	157.5
1,320	17.28	26.15	261.5	419.0
1,330	35.01	45.66	456.6	875.6
1,340	56.31	74.02	740.2	1,615.8
1,350	91.73	112.07	1,120.7	2,736.5
1,360	132.42	143.55	1,435.5	4,172.0
1,370	154.69	172.71	1,727.1	5,899.1
1,380	190.74	212.15	2,121.5	8,020.6
1,390	233.56	255.69	2,556.9	10,577.5
1,400	277.82	....	....	....

The Quicksilver mine reservoir site, while of satisfactory capacity, is not considered a feasible proposition because of the character of the dam site.

GIBRALTAR SITE.

DISCHARGE.

The Gibraltar reservoir site is situated 6 miles below the mouth of Mono Creek on Santa Ynez River. The drainage area tributary to it includes all of the Mono, the main river above the Mono, and 17 square miles additional. The discharge as estimated from the rainfall for the seasons from 1867–68 to 1903–4, inclusive, is shown in table 12 (see p. 53), and as measured[a] for 1902–3 in table 13 (see p. 54). From these it appears that the discharge is from 1.8 to 2.4 times as great as that of the Mono.

CONTENTS AND COST OF DAMS.

The reservoir site, which is shown in fig. 10, lies along a narrow, canyon-like valley with a light grade. The dam site is a rather peculiar and unusual one. An anticlinal fold of sandstone, apparently uplifted through the shales, has been cut by the river in a narrow gorge, as shown in Pl. VIII, *A* and *B*. The crest of this fold is almost level and

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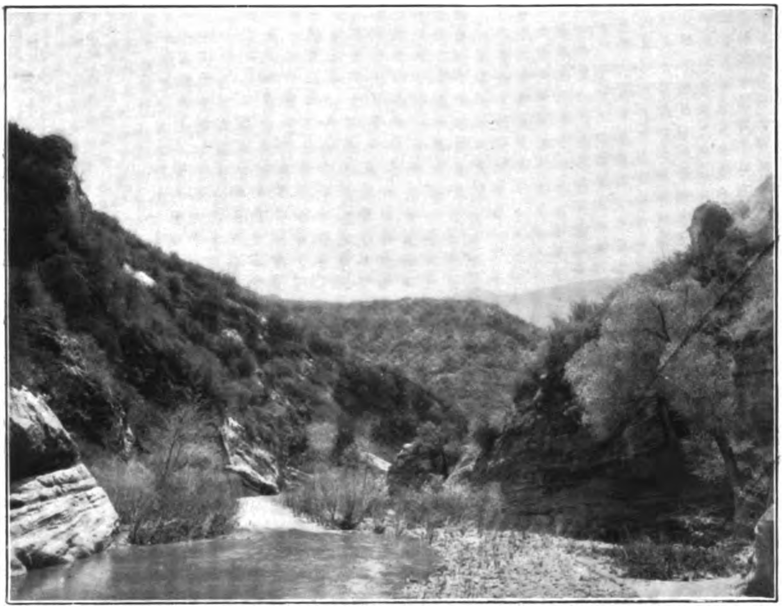
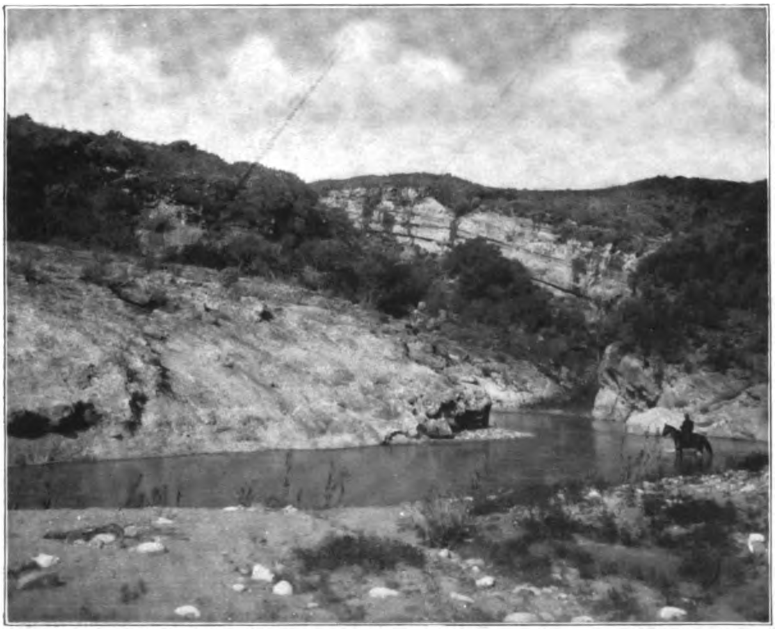
[a] Partly estimated.



A. GIBRALTAR DAM SITE, LOWER END OF GORGE.

View upstream.



B. GIBRALTAR DAM SITE, UPPER END OF GORGE AT PROPOSED AXIS OF DAM.

View downstream. Stream turns abruptly to the left. The spillway site is over the crest on the left.

is approximately 150 feet above the bed of the stream, so that a dam built slightly higher than the crest, or, say, 155 feet, will have the advantage of a natural spillway of great length on the side away from the dam and over solid rock. This is the only dam site that has been found in the upper portions of Santa Ynez River where the abutments are of a satisfactory nature and where the building material could be gotten out in such sizes and shapes as may be desirable for the construction of any type of dam.

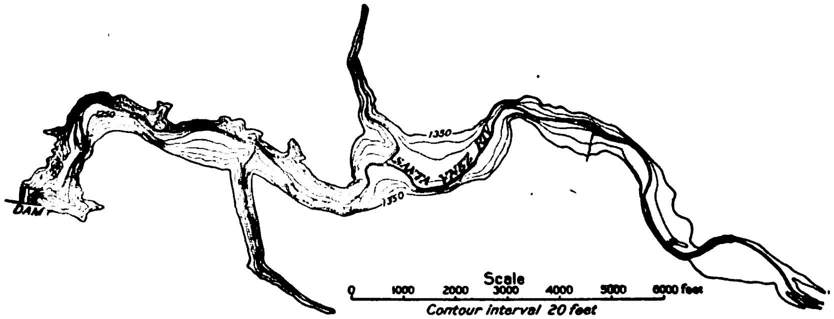


FIG. 10.—Gibraltar reservoir site.

A determination of the specific gravity of this rock has been made by weighing the rock first in air and then in water, which gave a specific gravity of 2.56. Four tests were made, ranging from 2.55 to 2.57. This is equivalent to a weight of 160 pounds per cubic foot. In rubble masonry, one-third of the bulk being mortar and two-thirds solid rock, and the mortar being considered as weighing 103 pounds, the weight would be 140 pounds per cubic foot of masonry in dam.

The ledges are in such a position as to permit a most economical handling of material for masonry construction.

TABLE 18a.—*Capacity of Gibraltar reservoir site.*

[Elevation of surface of stream bed, 1,215 feet.]

Contour.	Area in acres.	Average area in acres.	Capacity in acre-feet.	
			Between contours.	Total to contours.
1,215	0			
1,220	2.12			
1,230	5.74	3.93	39.3	39.3
1,240	13.26	9.50	95.0	134.3
1,250	22.67	17.97	179.7	314.0
1,260	32.37	27.52	275.2	589.2
1,270	50.11	41.24	412.4	1,001.6
1,280	66.24	58.17	581.7	1,583.3
1,290	90.06	78.15	781.5	2,364.8
1,300	119.62	104.84	1,048.4	3,413.2
1,310	152.74	136.18	1,361.8	4,775.0
1,320	188.33	170.53	1,705.3	6,480.3
1,330	227.13	207.73	2,077.3	8,557.6
1,340	271.39	249.26	2,492.6	11,050.2
1,345	296.64	284.01	1,420.0	12,470.2
1,350	332.75	314.70	1,573,5	14 043.7
1,355	367.07	349.91	1,749.6	15,793.3

Table 19 shows the volumes of material for a rock-fill dam situated at the Gibraltar reservoir site, the upper slope to be 1½ to 1, the lower slope 1¼ to 1, the width on top 20 feet, and the height of dam 155 feet, or 10 feet above the level of the spillway. The top of the crest is taken to be at the 1,360-foot contour. Bed-rock conditions are unknown, but for the purpose of this estimate are assumed to be at 1,205 feet. Repeated efforts were made to provide for an exploration of bed rock at this dam site, but owing to financial conditions and negotiations for the purchase of the property by the city of Santa Barbara it was not possible to arrange for this. The capacity with this dam to the 1,350-foot contour in the reservoir would be 14,044 acre-feet. Fig. 11 shows the plan for a 155-foot rock-fill dam.

In the table 7,444 cubic yards are deducted from the total estimated volume in the dam, as the rock fill will go down only to the 1,210-foot contour, except where the toe walls are located, where they are assumed to go as low as the 1,205-foot contour. The excavation of the spillway is taken at 1,250 cubic yards, which of course would be used in the construction of the dam. The spillway could probably be made much wider, if desired, in excavating the material for the dam. In this estimate it is taken as 350 feet in width.

A dam of this type is considered as having 12,083 cubic yards in asphalt-concrete face and dry-laid wall, this face to be put on as indicated in the drawing and to be covered by the dry-laid wall, to protect it from the sun, so as to prevent the movement of the asphalt. If this volume is deducted from the total yardage given in the dam, in addition to the deduction mentioned above on account of the rock-fill dam not going down to bed rock for its entire length, the net volume of rock fill will be 233,724 cubic yards.

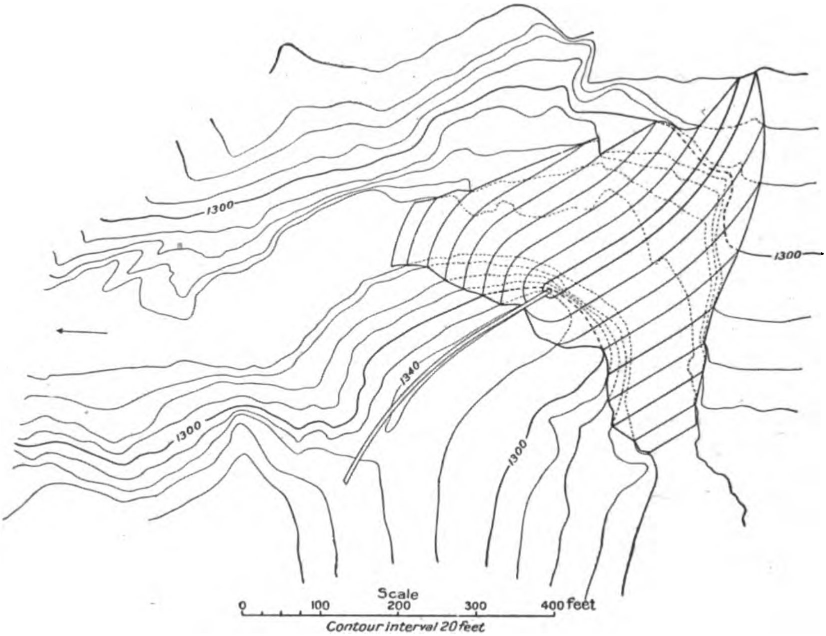


FIG. 11.—Gibraltar dam site, showing plan for 155-foot rock-fill dam.

TABLE 19.—*Volume in rock-fill dam at Gibraltar dam site.*[a]

[Capacity to 1,350-foot contour, 14,044 acre-feet.]

Contour.	Volume between contours in cubic yards.	Contour.	Volume between contours in cubic yards.
[b]1,205	....	1,320	15,231
1,210	7,444	1,330	13,194
1,220	14,713	1,340	10,916
1,230	16,648	1,350	8,148
1,240	19,805	1,360	4,796
1,250	21,536	Total..	253,251
1,260	22,185	Deduct[c]...	7,444
1,270	21,860		
1,280	20,925		245,807
1,290	19,981	Deduct[d]..	12,083
1,300	18,768	Net.......	233,724
1,310	17,101		

[a] Contents of spillway masonry dam=1,250 cubic yards. Spillway dam, 5 feet wide on top: 0.05 to 1 slope on upstream face; 10 feet down, 7 feet thick; 15 feet down, 9 feet thick; 20 feet down, 13 feet thick. Spillway is 350 feet in width; in excavating for dam it may be made wider, the limit in width being the limit of excavations.

[b] Bed rock as estimated, but not determined.

[c] Rock fill goes only to 1,210-foot contour.

[d] Asphalt face and dry-laid wall.

The hand-laid facing on top of the asphalt-concrete is estimated to be 3½ feet thick and the asphalt-concrete 1½ feet, covered with an impervious layer of asphalt two-tenths of a foot thick. The concrete cut-off wall at the upper toe of the dam is estimated as 90 feet long, with a height above assumed bed rock of 5 feet and a thickness on top of 5 feet, downstream vertical, upstream with a slope of 1 to 5 and a thickness at base of 6 feet.

The outlet system would consist of a tower reaching from the 1,220-foot contour to the 1,360-foot contour, a height of 140 feet. The internal diameter of the tower would be 8 feet at top and the thickness of wall 2 feet at top and 6 feet at bottom, the tower standing on a solid concrete base 5 feet thick and 21 feet in diameter. Following is an estimate of the cost:

Estimate of cost of 155-foot rock-fill dam at original site of Gibraltar dam.

Rock fill, 233,724 cubic yards, at 60 cents..................................	$140,234.00
Hand-laid facing, 8,458 cubic yards, at $1.60..........................	13,533.00
Asphalt and concrete facing, 3,625 cubic yards, at $8......................	29,000.00
Cut-off wall..	1,493.00
Overflow weir and subsidiary dam, 1,250 cubic yards, at $9...............	11,250.00
Clearing reservoir site, 333 acres, at $25................................	8,325.00

Outlet system:		
Tower, 911 cubic yards, at $9.30	$8,472.00	
Inlet pipes	460.00	
Valve rods	860.00	
Outlet valves	1,000.00	
Outlet tunnel, 1,000 feet, at $5	5,000.00	
Tower house and bridge	500.00	
Total of outlet system		$16,292.00
		220,127.00
Contingencies, 10 per cent		22,012.70
Engineering, 5 per cent		11.006.35
Total		253.146.05

The rock-fill dam can be built only to such height as will permit complete spillway opportunities around the end of the dam. It is, however, feasible to build a masonry dam that will not be the full height, permitting the water to waste over the top of the dam during different stages of its construction. For instance, the dam could be built to a height of 50 or 100 feet, and construction stopped until the demands or desires of the city should call for its completion; the final structure could then be built to its ultimate height of approximately 155 feet. When the dam was completed to its full height the overflow and waste water could then be directed through the spillways.

If such a dam should be built of cyclopean rubble masonry on a gravity section and also on a curve, the top would stand at the 1,560-foot contour. The estimate given below is based on bed rock being at a depth of 5 feet beneath the present stream bed, but it is not known what the depth actually is, and the final estimates might be greatly modified by these conditions. A determination of this point is essential before beginning the construction of the dam and before the final estimate on its cost can be made.

Three estimates have been prepared on the assumption that the dam will not be built to its full height from the start. These are for dams 95 feet high, with a capacity of 3,413 acre-feet, equivalent to a continuous flow of 4.715 second-feet, or 236 miner's inches per annum; 125 feet high, with a capacity of 8,558 acre-feet, equivalent to a continuous flow of 11.82 second-feet, or 591 miner's inches per annum; and 155 feet high, with a capacity of 15,793 acre-feet, equivalent to a continuous flow of 21.81 second-feet, or 1,090 miner's inches per annum.

These estimates of discharge are on the assumption that the reservoir would be filled by the stream every year. This, however, can not be done, for in some winters there will be little more addition to the reservoir than enough to make up for evaporation. If it is assumed that the 155-foot dam is built, and that its capacity is

15,793 acre-feet, and that this will have to furnish the supply of water for nineteen months, the yield will be 831 acre-feet monthly; with the reservoir half full the monthly loss by evaporation would average about 66 acre-feet, leaving 765 acre-feet monthly for distribution during the dry period, or a continuous flow of 13 second-feet, equivalent to 650 miner's inches, or 8,400,000 gallons daily. Putting it another way, the flow will be approximately 900 miner's inches in the summer time and 400 miner's inches in the winter time. Fig. 12 shows a plan of a 155-foot masonry dam.

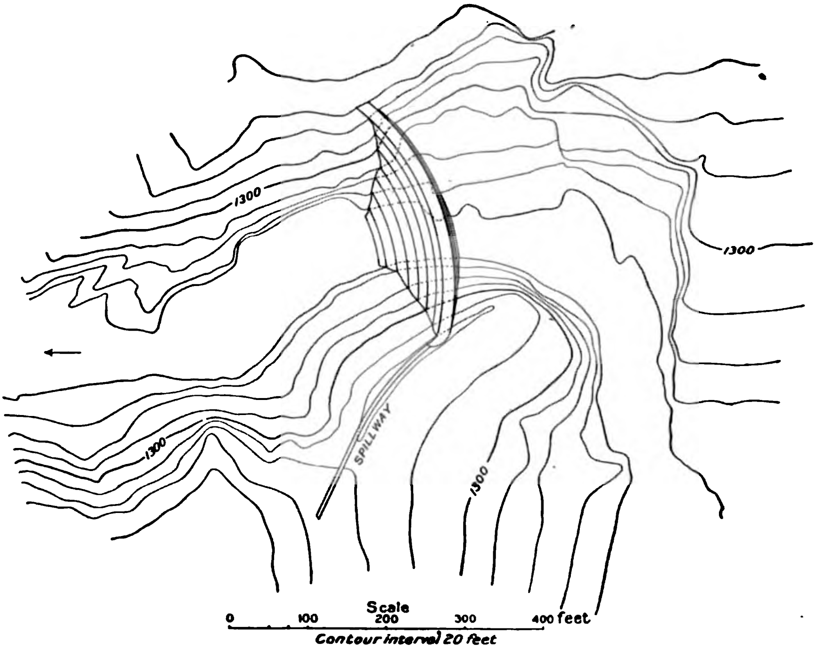


FIG. 12.—Gibraltar dam site, showing plan for 155-foot masonry dam.

With the lower size dam the surplus water is considered as wasted over the top of the dam, and the dam is made safe on the gravity section with 10 feet of water passing over its crest; in addition it is to be a curved dam. These same conditions will obtain with a dam 125 feet high. The 155-foot masonry dam is designed to let the surplus water pass through a spillway, the water standing within 5 feet of the top of the dam, and the capacity being 15,793 acre-feet. This is a greater capacity than that for the 155-foot rock-fill dam, because with the rock-fill dam greater safety in spillway capacity would be required, and this type would have to be built at least 10 feet above the level of the spillway. Figs. 13, 14, and 15 give sections of the dams considered. In the estimates masonry weighing 140 pounds per cubic foot is used.

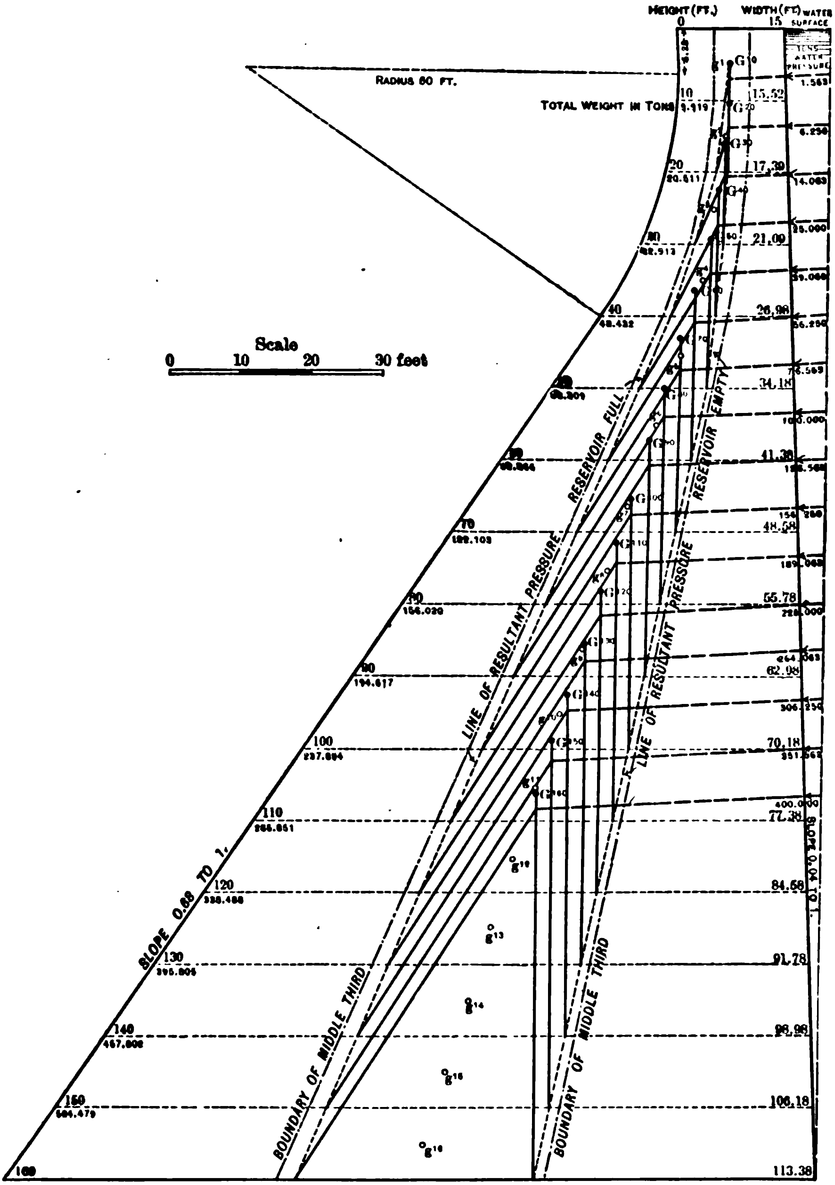


FIG. 13.—Section of masonry dam for Gibraltar reservoir based on concrete weighing 130 pounds per cubic foot.

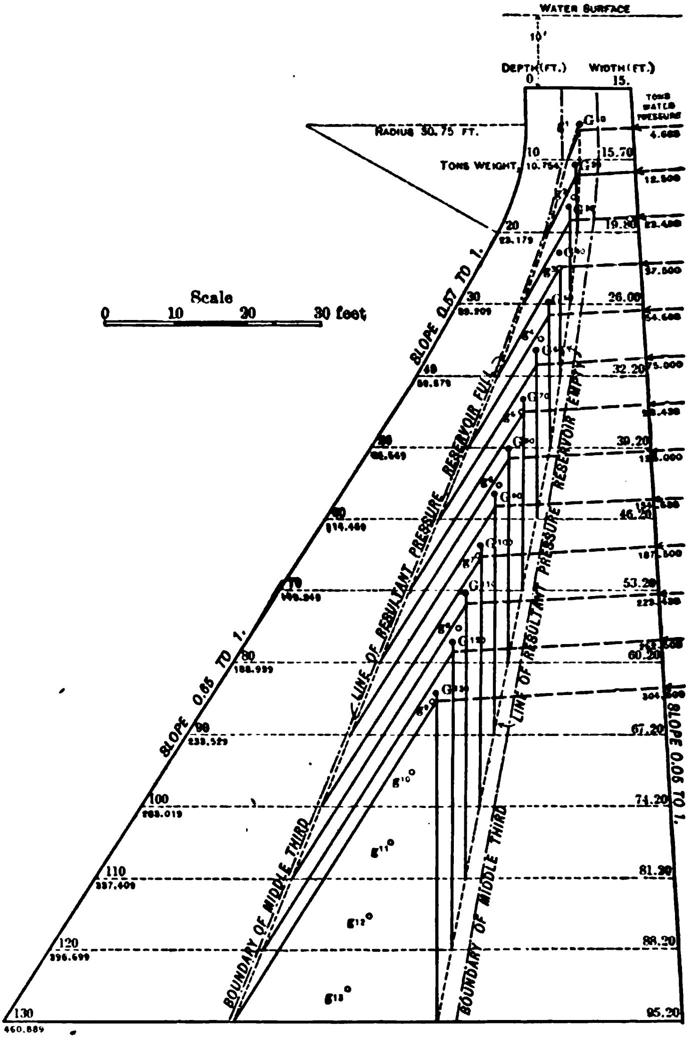


FIG. 14.—Section of masonry overflow weir dam based on masonry weighing 140 pounds per cubic foot.

The following is an estimate on three types of dams:

Estimate of cost of 95-foot masonry overflow dam located at lower site of Gibraltar dam.

[Capacity 3,413 acre-feet.]

Masonry, 15,331 cubic yards, at $7	$107,317.00
Excavation to bed rock, 1,280 cubic yards, at $2.50	3,200.00
Clearing reservoir, 120 acres, at $25	3,000.00
Outlet system, tower, gates, tunnel, etc	9,971.00
	123,488.00
Contingencies, 10 per cent	12,348.80
Engineering, 5 per cent	6,174.40
Total	142,011.20

Cost per acre-foot of capacity, $41.61.

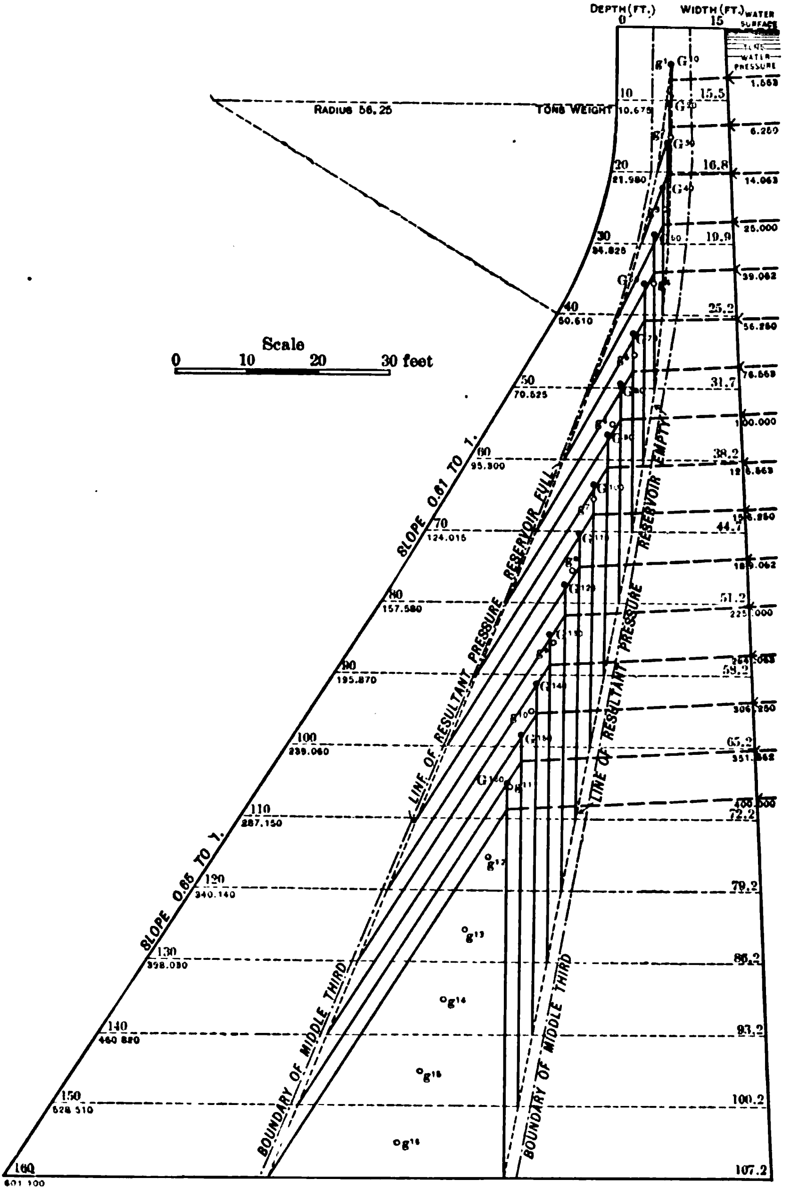


FIG. 15.—Section of masonry dam based on masonry weighing 140 pounds per cubic foot.

Estimate of cost of 125-foot masonry overflow dam located at lower site of Gibraltar dam.

[Capacity 8,558 acre-feet.]

Masonry, 27,971 cubic yards, at $7	$195,797.00
Excavation to bed rock, 1,579 cubic yards, at $2.50	3,948.00
Clearing reservoir, 227 acres, at $25	5,675.00
Outlet system, tunnel, gates, tower, etc	13,000.00
	218,420.00

Contingencies, 10 per cent	$21,842.00
Engineering, 5 per cent	10,921.00
Total	251,183.00

Cost per acre-foot of capacity, $29.35.

Estimate of cost of 155-foot masonry dam located at lower site of Gibraltar dam.

Masonry in dam, 42,250 cubic yards; masonry in spillway, 833 cubic yards; masonry in protection wall, 56 cubic yards; total masonry, 43,139 cubic yards, at $7	$301,973.00
Excavation to bed rock, 1,731 cubic yards, at $2.50	4,328.00
Clearing reservoir, 350 acres, at $25	8,750.00
Outlet system, tower, gates, tunnel, etc	16,292.00
	331,343.00
Contingencies, 10 per cent	33,134.30
Engineering, 5 per cent	16,567.15
Total	381,044.45

The flood discharge from these drainage basins is considered in the discussions of the spillway for the Mono reservoir site. Taking a maximum flood discharge of 130 cubic feet per second per square mile from the entire 207 square miles that are tributary to the Gibraltar reservoir site, the spillway of 600 feet in length would be running full and the water passing 3½ feet deep over the top of the masonry dam. This would be a most extraordinary flood, and it is believed that the dam, with the gravity section that it has, in addition to its arched shape, would stand this.

In the case of the 125-foot dam such a flood would pass over the crest of the dam 9½ feet deep, and the dam is designed to withstand with safety an overflow of 10 feet on a gravity section without the aid of its curved shape.

For the 95-foot dam under similar conditions the depth of water would be 11 feet.

TUNNELS TO GIBRALTAR SITE.

Because of its elevation and location it will not be possible to use the old city tunnel in Cold Spring Canyon in reaching the Gibraltar reservoir site. The elevation of the surface of the water at the Gibraltar, with a dam 155 feet high, is 1,360 feet above sea level, and the estimated elevation of the northern end of the old Cold Spring Canyon tunnel at its northern portal would be 1,457 feet. The location also is not suitable for the Gibraltar site. Because of these facts, a new tunnel location was sought as an outlet for the Gibraltar reservoir site. The triangulation was extended so as to cover the distance intervening between Mission Canyon and the Gibraltar dam site, and it was found that a tunnel from Mission Canyon to the Gibraltar would be 19,560 feet in length, and from Rattlesnake Canyon to the

Gibraltar it would be 20,763 feet in length. The length necessary to complete the old tunnel from Cold Spring Canyon through to Santa Ynez is 14,901 feet. It must be remembered, however, that the old tunnel has very irregular grades, that the cross section of it is not uniform, and that the alignment is irregular. In addition to that, the present heading is 5,000 feet from the portal, so that the total length of the Cold Spring Canyon tunnel, if completed, would be 19,901 feet. Because of these irregularities in the old tunnel and the distance in from the heading, it has been estimated that the cost to complete it would be at the rate of $12 a foot; the total cost of completing it, building roads, engineering, etc., having been previously estimated at $212,833 (see p. 77).

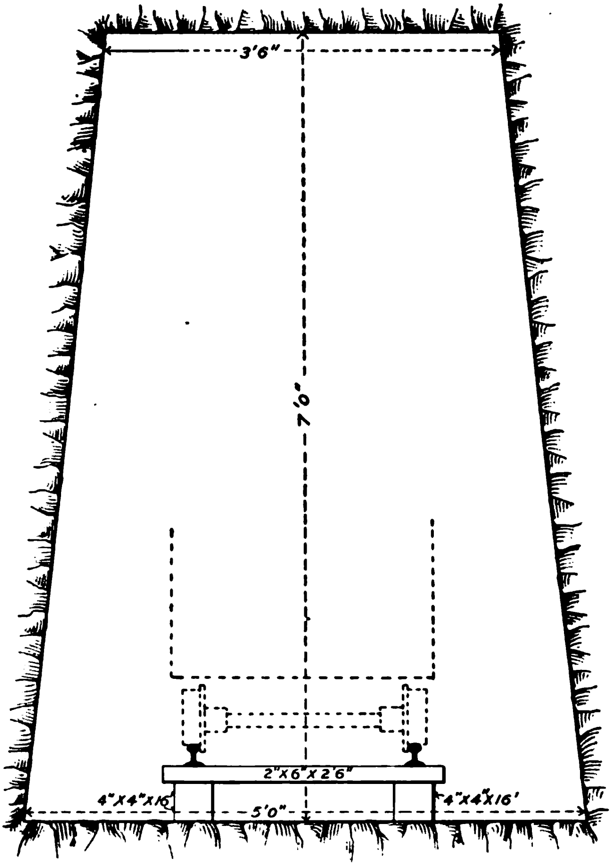


FIG. 16.—Section of new Santa Barbara tunnel in solid rock.

The following is an estimate of the cost of building the Mission or the Rattlesnake tunnel.[a]

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[a] Since writing the above, contracts have been entered into for the construction of the Mission Canyon tunnel line at a figure slightly below this estimate (see p. 43). Figs. 16 and 17 show sections of this tunnel.

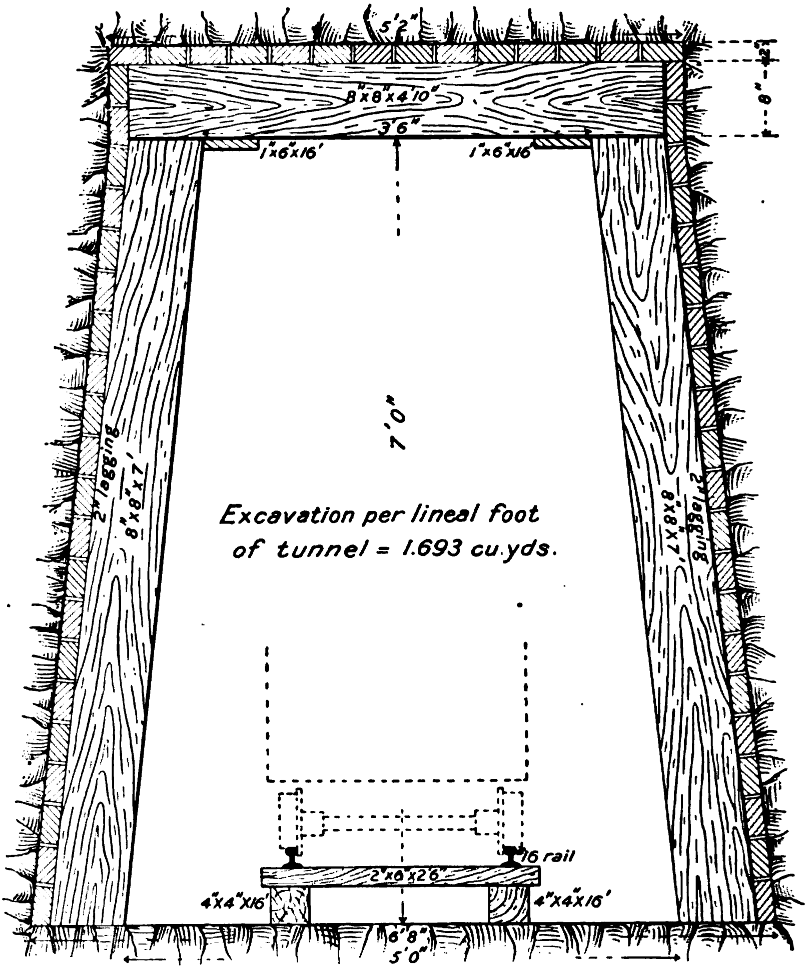

FIG. 17.—Section of new Santa Barbara tunnel in loose rock.

Estimate of cost of building Mission Canyon tunnel.

[Length based on triangulation by L. M. Hyde.]

19,560 linear feet, at $10 per linear foot	$195,600
Road up Santa Ynez River	2,500
Road up Mission Canyon	2,500
Engineering, 5 per cent	10,030
Contingencies, 10 per cent	20,060
Total estimated cost	230,690

Estimate of cost of building Rattlesnake Canyon tunnel.

[Length based on triangulation by L. M. Hyde.]

20,763 linear feet, at $10 per linear foot	$207,630
Road up Santa Ynez River	2,500

Road up Rattlesnake Canyon	$3,500
Engineering, 5 per cent	10,682
Contingencies, 10 per cent	21,363
Total estimated cost	245,675

COMPARISON OF GIBRALTAR AND MONO SITES.

In order to compare the costs of the combined tunnel and reservoir for the Gibraltar site and for the Mono site, the following table is given:

TABLE 20.—*Comparative estimates of dams and tunnel lines at Gibraltar and Mono.*

GIBRALTAR.	
95-foot masonry overflow dam (3,413 acre-feet, at $41.61)	$142,012
19,560 feet of tunnel (Mission line)	230,690
Total	372,702
125-foot masonry overflow dam (8,558 acre-feet, at $29.35)	251,183
19,560 feet of tunnel (Mission line)	230,690
Total	481,873
155-foot masonry dam (15,793 acre-feet, at $24.13)	381,044
19,560 feet of tunnel (Mission line)	230,690
Total	611,734
155-foot rock-fill dam (15,793 acre-feet, at $16.02)	253,146
19,560 feet of tunnel (Mission line)	230,690
Total	483,836
MONO.	
85-foot rock-fill dam (3,880 acre-feet, at $36)	140,700
15,006 feet of tunnel	212,833
Total	353,533
110-foot rock-fill dam (8,670 acre-feet, at $24.40)	211,586
15,006 feet of tunnel	212,833
Total	424,419
85-foot masonry dam (3,880 acre-feet, at $93.22)	361,690
15,006 feet of tunnel	212,833
Total	574,520

The masonry dam is the better form of construction for a storage reservoir. In addition the abutments at the Gibraltar reservoir site are much more secure and satisfactory than at the Mono site. The water supply is more than twice as great at the Gibraltar as at the Mono and its quality is better.

Making the comparison for masonry dams, it will be seen that the cost for the 155-foot masonry dam at the Gibraltar site would be

$24.13 per acre-foot of water impounded, while for the 85-foot masonry dam at the Mono site it would be $93.22 per acre-foot.

With a 125-foot masonry dam at the Gibraltar, the capacity of the reservoir would be 8,558 acre-feet, and the total estimated cost of the dam and tunnel would be $481,873.

A 110-foot rock-fill dam at the Mono would have a capacity of 8,676 acre-feet, and with the completion of the Cold Spring tunnel would cost $424,419, which is less than the cost of the Gibraltar 125-foot dam. The Gibraltar dam, however, would undoubtedly be safer, have fully twice the water supply available for dry years, and would furnish better water. These things considered, there can be no doubt whatever that it is advisable to construct the Gibraltar dam with the Mission Canyon tunnel, rather than the Mono site with the completion of the Cold Spring Canyon tunnel.

The real governing factor in the entire situation is the quantity and quality of the water, and on this basis there can not be any doubt that the Gibraltar site is far the better. During the winter of 1902–3 the total discharge of Mono Creek at the Mono reservoir site was 8,934 acre-feet, while at the Gibraltar it was 21,202 acre-feet, or 2.4 times as much. In addition the situation is such at the Gibraltar site that the masonry dam can be gradually built higher as the demand of the city for a greater water supply grows, while there are distinct limitations to the construction of a higher dam at the Mono site.

FINANCIAL STATEMENT.

The financial results to be expected from the expenditure of the money necessary to build the work above referred to are not extensively considered, because it is not so much a question of whether these works can be constructed at a commercial profit as it is a question of how much it will cost to get an adequate water supply for the locality. It goes without saying that if the coast district is to continue to grow it must have water, and the only question is whether this can be obtained at reasonable cost.

The output from this system should be 1½ million gallons daily for 10,000 people. On page 25 it is shown that in order to meet the worst-known drought of nineteen months and deliver 150 gallons daily for 10,000 persons, plus the evaporation, a storage capacity of 3,518 acre-feet is required. This is on the assumption that all of the water must come from the reservoir and none can be obtained from the tunnels or streams on the south side of the range, a condition which the writer believes never will exist, but which he assumes for safety. At the Gibraltar site a dam 95 feet high will practically accomplish this at a cost for dam and tunnel of $372,702. Assuming an interest rate of 4½ per cent on this cost, we shall have an annual fixed charge of $16,772. The works will all be permanent. Construction and maintenance charges should be very low, say $4,000 per annum. Operation should not be over $2,000. This gives a total annual charge of $22,772 for 547 million gallons, or a maximum of 4.1 cents per 1,000 gallons delivered at the intake of the domestic system. As the dam is increased in height the cost per unit of storage and the proportional charge for the tunnel will rapidly decrease with the resulting increased supply. With a dam 155 feet high on the above basis the cost per thousand gallons would be 1.1 cents. The long tunnel will undoubtedly also itself contribute a material supply to the city. Mr. Canfield, the president of the Santa Barbara Water Company, states as follows:

> Water is now sold in Santa Barbara at the rate of about 16 cents per thousand gallons to the city for street-sprinkling purposes (at the rate of $35,000 per year for 1 second-foot), and to private consumers at from 20 cents to 25 cents per thousand gallons, which are moderate rates as compared with those realized in some other cities in this State, and it is believed that although the development of the business in the future may justify some reduction of rates, an average rate of 15 cents per thousand gallons at least can be calculated upon.

This is certainly a very reasonable charge for water in southern California. The lowest meter rate known in the State (that of the city of Los Angeles) is 9 cents per 1,000 gallons delivered to the consumer. Of course, there must be an intermediate charge for distribution system and administration which comes after the water is delivered to the mains.

Both Mr. Wright and Mr. Purslow considered the construction of these storage reservoirs as a profitable investment from a commercial standpoint. If the water was delivered free at sea level to the city, it would cost two-thirds as much for fuel alone (say 2.7 cents), with triple-expansion engines, to pump it to the city reservoir as it would to obtain it from this contemplated system of storage reservoirs. If interest, depreciation, and services are considered it would cost more to pump it.

There would undoubtedly also be a very considerable element of profit that might be derived from the water power available from the supply, since the elevation of the southern portal of the tunnel is approximately 1,200 feet and the elevation of the domestic reservoirs only 350 feet.

The result of the construction of the long tunnel probably will be the construction of the dam to the maximum height commensurate with the water supply of Santa Ynez River by the city, or by other parties who might make arrangements with the city for carrying water through this long tunnel. This should be a condition that the city would encourage.[a] The water not required by the municipality would be used in developing and irrigating the beautiful coast plain near Montecito or in other adjoining localities. The improvement of this region would, of course, add to the prosperity of the county and city of Santa Barbara.

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[a] Since writing the above the city has entered into a contract with the Santa Barbara Water Company to permit of such a use of the city tunnel by the company.

In this report estimates on right of way have not been included.

CONCLUSIONS.

In conclusion it may be stated—

(1) That the only extensive addition that can be made to the water supply of the Santa Barbara coastal plain is by the construction of a tunnel from Santa Ynez River to the coast side of the mountains and the building of an impounding reservoir for the holding of the winter flood waters of Santa Ynez River.

(2) That by far the most desirable point on Santa Ynez River for this construction is the Gibraltar reservoir site.

(3) That the water can be delivered at a reasonable cost for both irrigation and domestic use to Santa Barbara and vicinity from this site, and the construction is believed to be entirely justified and commercially feasible.

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Series.

U. S. Geological survey.

Water-supply and irrigation papers.

no. 116. Lippincott, J. B. Water problems of Santa Barbara, California. 1905.

Reference.

U. S. Dept. of the Interior.

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U. S. Geological survey.